

ELEMENTS OF GENERAL SCIENCE

CALDWELL AND EKENBERRY



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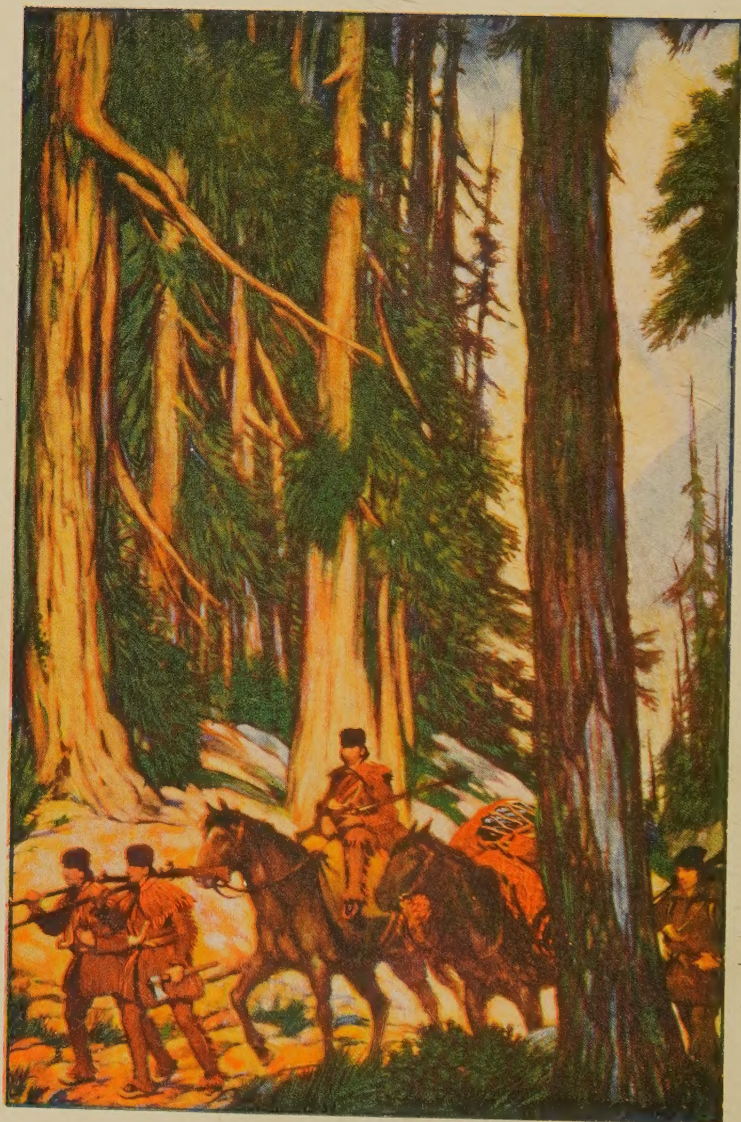
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HOW THE FATHERS TRAVELED

ELEMENTS OF GENERAL SCIENCE

BY

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PREFACE

About two decades ago it became clear to educators that the highly refined and intensive special sciences did not provide the best introductory courses. Several independent experiments were started in the effort to discover the kinds of subject matter, organization, and presentation which are of greatest educational value. Unprecedented numbers of young people were, and still are, coming into modern high schools. Most of these wanted and needed good general education, which might or might not be followed by further work in high-school science or by later science studies in college. They needed a course in science which would be best for their years, independent of what might follow. Such a course was developed, and it has succeeded in ways which give the greatest encouragement to those who genuinely desire to improve American education. Furthermore, the success of this course has resulted in improvement in other courses in science and thus has helped science-teaching generally. Since the course is now more widely used than any other course in science has been, its good influence is very large.

The course outlined in this book represents the results of more than fifteen years' experiment and coöperative criticism in secondary schools. It has been developed by persons interested in and engaged in secondary-school work, and hundreds of public-school teachers have made important contributions to the present content and form of the course. Teachers of subjects other than science and administrative officers who are studying the efficiency of the whole high-school curriculum have helped greatly through their constant observation and constructive criticism of the course as it has developed. The course in its present form is therefore the result of coöperative efforts of many science teachers who believe that the method of

experimental science must be used in the selection of the essential topics, in their organization, and in testing the results of courses in science-teaching.

Human experience includes results of modern science almost constantly. The scientist's way of working and thinking is recognized and desired as the most reliable method. It is also generally recognized that science in the schools should lead to better understanding and better daily use of the kinds of scientific knowledge which are associated with common human experience. It is the object of this course to develop a usable fund of interesting and worth-while knowledge about common things. It is also its object to develop helpful and trustworthy habits of thinking about and of judging the common experiences which fall within the fields of science. Particular interests and abilities of pupils are frequently revealed in science studies, and by recognizing and directing them more effective and more profitable work may be accomplished in vocations or later studies.

In this course no attempt is made to use the so-called unity of any particular special science. Rather is unity secured by use of the logical interrelations between the topics which compose the course. Experience shows that after use of this course pupils do not feel that they "have had" any of the differentiated sciences, such as physiography, physics, chemistry, or biology. They are, however, much interested in the later study of the differentiated sciences. The topics of the course are readily grouped under six major divisions. Within these major divisions the topics are arranged so that there is coherence and progression in the work. The authors have selected the materials and have organized the course upon the ground of pedagogical value, as shown by classroom experiment.

The general topic headings are those of the earlier edition of this book, since those have been found by experience to be the ones of most common approval in use. Much new material has been added; for example, that on gas and electric engines, discussions of radio work, added topics in hygiene and health, vitamin studies, and many others. Seventy-eight new illustra-

tions are included, together with nearly all those which were in the preceding edition, there being a total of some fifty more than formerly. The book is somewhat larger, in response to a common judgment of the best teachers to the effect that the general-science course requires a larger amount of engaging discussion of the topics considered. The book is wholly rewritten. Its vocabulary has been carefully compared with the standard eighth-grade vocabulary. All words not found in some form in the eighth-grade vocabulary have been omitted, excepting such as in the judgment of the authors are required by the nature of the subject and are desirable additions to the vocabulary of an eighth-grade pupil.

At the beginning of each chapter a list of questions for discussion is given. It is expected that when beginning the work of each chapter the pupils and teacher will read and discuss the questions briefly. These questions recall pupils' previous experiences and set up new problems whose brief consideration gives significant purpose to the text and experimental work which follows. It is not intended that much time will be used in these questions or that complete answers will be given to them. After the chapter has been studied, the questions provide the best means of review.

Throughout the course there should be experimental work in the form of demonstrations, individual or group laboratory exercises, and home or school projects. A laboratory manual has been prepared to serve as a guide in the performance of experiments and demonstrations. The apparatus for use in experiments should be the most simple available, and that from the community or home may often be more educative than complex and costly apparatus.

The authors wish to record but cannot fully express their appreciation for valued assistance given by Professor F. R. Moulton of the Department of Astronomy, The University of Chicago; to Professors W. B. Owen of the Chicago Teachers College and F. W. Johnson of Columbia University, under whose administrative guidance and encouragement the first

trying years of experimentation in high schools were carried on; to Professor Allan W. Abbott of Columbia University for reading and improving the English form and style of the manuscript; to Mrs. Rose Flentje for highly important vocabulary studies conducted with patience and helpfulness; to Mr. Earl R. Glenn and Mr. Charles W. Finley of the Lincoln School, Teachers College, for constant classroom help. Most of all do the authors express their appreciation to the many former students and to many high-school teachers who have frankly and sympathetically given assistance in helping to develop science-teaching, in which this book is but one of the stages of progress.

OTIS W. CALDWELL

W. L. EIKENBERRY

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GENERAL SCIENCE

PART I. THE AIR

CHAPTER I

SCIENCE IN THE MODERN WORLD

1. How the fathers traveled. A little more than a hundred and fifty years ago Daniel Boone and four companions began a journey from North Carolina to the region then known as Kentucky. The trip was planned to explore a country which rumors from earlier wanderers had described as a land of unusual promise for ambitious, daring, and hardy settlers. The trail westward was poorly marked and little known. It led over mountains, through primeval forests, and across wide streams where bridges were unknown. Boone and his companions walked on this trip, as did most long-distance travelers of their day. A few pack horses carried all necessary equipment for the months which were required for the trip. Encounters with Indians and other misfortunes caused the men to lose their pack horses and almost all their equipment. All but one of the men left Boone and returned eastward. There followed two years of tramping amidst dangers and hardships which today are unknown and almost unbelievable. These were years during which food, clothing, and shelter were secured from native streams and forests. Boone then returned afoot to make his report of the wonderful new lands he had seen and of his proposed wilderness roadway to the westward.

This and later journeys by Boone and by other foot travelers were followed by caravans of settlers. Some walked, and some

rode on horseback part of the time, though at first horses were used chiefly as pack animals. Sometimes two persons with one horse would "ride and tie." This meant that one would ride ahead on the trail, and tie and leave the horse for the walker to use when he reached this place. The first man, having then walked ahead after leaving the horse, would later be passed by the horse and the second rider. By thus taking turns in riding and walking, an easier and more rapid journey could be made by both travelers.

Certainly travel a century and more ago was difficult and slow. Much credit is due to those who entered and developed the great stretches of fertile lands which now feed so much of the world. The early trails soon became well marked, then rough roadways were made, and now, after many years and much effort, there are many highways across the entire country.

2. Modern travel. Nowadays, if one does not have time or is not inclined to use the highway, he may take a train from points which are even farther east than Daniel Boone's starting point, and on the morning of the following day may be in the Kentucky region, which was Boone's goal. Or, by continuing his railroad journey, he may in four days be upon the Pacific coast, a journey which in an early day required many months. The lives of many thousands of those who first undertook to cross the continent were lost. The early trail was partly marked by the graves of those who failed to reach the Western regions.

The early travelers secured their food, clothing, and shelter from the forests. They were their own motive power, slowly transporting themselves from place to place. They carried their baggage or took care of the pack animals which carried it. The modern traveler sleeps as he travels. He is served with food abundantly and attractively. With early travelers physical exercise was superabundant, food hard to get; with modern travelers exercise is easily avoided, food abundant. The pleasures and dangers of modern long-distance travel are clearly quite different from those of the olden times.

The construction and operation of an automobile or of a single modern railway train require the use of thousands of scientific discoveries and inventions. If we did not possess the results of modern science, we should still be traveling as the early settlers did, if we traveled at all.

3. Flying-men. As the modern railway train speeding across the continent has made transportation on the old trails seem slow, so has the still more modern *aéroplane* caused the train to seem slow. To say, as once was said, "You can no more do that than you can fly" means little now, for men can now fly. They fly to a height probably many times greater than that ever reached by the most lofty bird and at speeds and over distances which constantly astonish us. Flying-men now carry government and private mails for thousands of miles. Regular passenger flying-routes are in operation. The proposition is made of establishing overnight flying-routes. If this were done, one might attend an evening's entertainment in one city, then spend the night on the *aéroplane* sleeper, and have his breakfast next morning in a city a thousand miles from the starting point.

Patient and heroic students of science have enabled men to fly. Studies of the air, of construction materials, of how forces work,—these and many others have slowly grown into this great scientific achievement.

4. Science and food. When the early settlers were fortunate enough to have more food than their immediate needs required, they were often unable to keep it for later uses. Even salt for preserving meat and fish was often not available. So rare was salt in the central states that at least one early transfer of land records that fifty bushels of salt was the purchase price of fifty acres of good land. In early days most fruits and vegetables could be had fresh only in the growing season, though cellars and burying-pits provided means of keeping some of the more resistant foods for use out of season. Apples, oranges, lemons, grapefruit, vegetables, etc. are now available throughout the year, owing to the many applications of the modern sciences of refrigeration, canning, drying, and other forms of preservation.

Food may now be grown when and where it is most advantageous, and may be sold when and where it is in most demand.

In countries or in times when it is extremely difficult to secure food enough, what people eat is determined largely by what they can get. The cravings of appetite may cause a desire for other food, but in severe conditions what people eat is not necessarily what they desire to eat. On the other hand, in time of plenty, appetite and habit largely determine the diet.

One type of science work has been successfully directed toward production of better food in larger quantity and in much wider range of kinds. This has led to a further and more important problem in the science of foods. That is, if food is reasonably abundant, is it safe to trust appetite for a guide as to the quantity and kinds of foods to eat? By making food more abundant and available throughout the year, availability of food, appetite, and habit are less the guide to nutrition, and real knowledge of the needed balanced ration is more to be depended upon. The scientific study of balanced rations is as important in feeding human beings as in feeding cattle and pigs. It is much more difficult to get human beings actually to use properly balanced rations for themselves than it is to get them to adopt balanced rations for their cattle and pigs.

Modern science has changed the geography of the world's food supply by teaching men to produce food where it will grow best, then to devise methods of transportation and preservation so as to get the food to the markets all over the world.

5. Science and communication. Once when Daniel Boone thought it necessary to send word back from the settlement in Kentucky to North Carolina, he sent one member of his party alone on the long and hazardous tramp to carry the message. Months were required for this message to reach its destination and still more months before a reply could be carried back to the Western settlement. If at that time someone had been bold and intelligent enough to advocate sending the message over wires, he would have caused great surprise, wonder, and disbelief. He would probably have been regarded as insane.

Modern wireless messages, music, addresses, weather and crop reports, are merely continuations in the long list of improvements in the science of communication. Someone has playfully but probably incorrectly said that we are developing more rapidly in how to communicate than we are in helpful ideas worth while to communicate.

The wonders of modern communication of ideas are more striking than were the things imagined by early scientists. When S. F. B. Morse sent his first land telegraph message he chose the words "What hath God Wrought." Some such thought must have occurred many times to many men who have observed how progress is made as we learn more and more of the true principles of nature and discover how to apply, to control, and to be controlled by those principles in the work of the world.

6. Science and truth. Science constantly tries to find out what is really true, and how those things which are true actually work in the affairs with which men deal. The development in transportation, in production and care of food, in communication, and in unnumbered other ways has come about through the constant and patient increase in understanding of the truth about men and things. There has been a great growth in people's desire to know and understand the facts of nature and in the desire to be guided by facts. Time was when many persons were afraid of nature. Ignorance and fear are rather constant companions, and as science enables people to learn more and more of truth, the uses of truth increase and the fear of nature declines.

Science has caused the modern world to advance with gigantic strides. Each day's experience of each person presents many manifestations of modern science. To live intelligently and most usefully everyone needs a considerable measure of understanding and appreciation of at least the more common and more engaging aspects of the science of modern affairs.

7. Large things easier to see than small ones. When first you saw an aëroplane you were struck with wonder, but you clearly understood that man had made a machine which could

fly through the air and at the same time could carry the man who made it. Attention was not primarily drawn to the endless structural details of wood and metal, to the mathematical problems involved in determining the nature and strength of supporting or propelling parts, to the nature of the fuel used nor how its burning operated the engine of the *aéroplane*, to how a human being can endure the changes in temperature or air pressure as he flies high in the air, nor to any one of a thousand other considerations which men of science had to study most carefully before an *aéroplane* could ever come into existence. If it were insisted that all details should be studied before you could know what an *aéroplane* is, interest would be lost long before much knowledge would be gained. Having seen the whole machine in operation first, you clearly know its nature and use; after this many students desire to study more and more of the details which have been developed in order that *aéroplanes* may be built.

Almost any topic in the study of science would illustrate the same point. We see large units, large ideas, first; then if we proceed, we add to our knowledge, each addition helping us to improve our first broad view.

Science is divided into many special fields, all of which are important. We shall study certain large topics or units in science with the hope of gaining useful and interesting knowledge and of seeing how scientists work in gaining new knowledge. More detailed studies in special sciences may come later for those who find them interesting and profitable.

8. How knowledge grows. The work of each generation of men and women adds much to the interesting and important things in the world. Almost any brief excursion away from your home presents new problems to you and raises questions about the new things you see and also about others with which you have been more or less acquainted. When carefully studied, some of the things with which we are acquainted seem quite as strange and quite as interesting as do things which we see for the first time.

This course should help pupils to find the answers, or perhaps to create the answers, to many questions and problems which people constantly meet. Some of these problems are so difficult that years of study would be required to understand them; other common problems have not yet been solved by anyone; but we shall deal almost wholly with problems which may be easily answered by careful study. You can secure answers to questions in science by asking someone who knows, or you may consult a book which treats of the subject, or you may answer the question by trying an experiment and then, after observing the experiment, thinking the matter out for yourself. People who study science use all three of these ways of answering questions. There are, however, many problems which can be solved only by use of the last way mentioned, and every person should become able to think things out for himself from his observations of common occurrences.

CHAPTER II

HOW AIR BEHAVES, OR CHARACTERISTICS OF THE AIR

9. Questions for discussion. 1. Why does smoke go up a chimney? 2. What are the reasons for placing furnaces in basements rather than in upper rooms of buildings? 3. What is the purpose of a chimney on a house? 4. How should the dampers in a stove or furnace be arranged when a fire is being started? 5. Why does a check draft in a range or furnace cause the fire to burn more slowly? 6. After a fire is started in a cookstove, what changes in the dampers should be made if the oven is to be heated?

7. Why is hot water drawn off from the top of the heater instead of from the bottom, near the fire? 8. Why does a cake of ice in a refrigerator thaw more rapidly at the top than at the bottom? 9. Why does a paper balloon with a lighted candle at the base tend to rise? 10. Why is a room cooled more quickly if a window is opened at the top than if it is opened at the bottom? 11. Would the change of air be more rapid if the window were opened at both top and bottom? 12. If a room is heated from a hot-air register in the floor at one side of the room, why does the opposite side of the room feel warm before the center?

13. If we press an inflated rubber ball and then release it, it will resume its original shape. Why? 14. When an empty bottle is suddenly submerged in water, air bubbles rise. Explain this fact. 15. Why does a tennis ball not bounce well after it has been punctured? 16. If air is a gas, why does it hold up the weight of an automobile? 17. What makes the popgun pop? 18. How do air brakes work?

19. Why is it easier to cook food in a closed vessel than in an open one? 20. Can you heat water to a temperature of 125°C . (or 257°F .)? If so, how? 21. How can the mercurial barometer be used in approximating the heights of mountains? 22. Explain the fact that some people have a pain in the head over the eyes and ears or have nosebleed when going up a high mountain.

23. A pupil in school is said to require about two thousand cubic feet of air space. Measure your schoolroom and determine the total volume of air in the room. 24. How may the proper amount of fresh air be secured in your schoolroom?

10. Knowing the air. Perhaps none of the things which surround us affect us so much or seem more puzzling than the air.

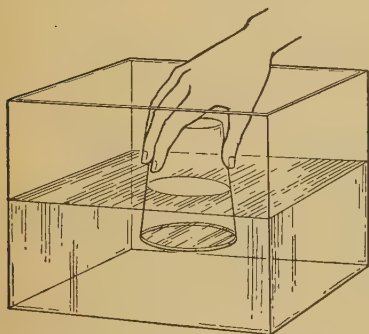


FIG. 1. Air occupying space

An experiment with an inverted glass showing that the air within the glass prevents the water from filling the glass

We feel rather well acquainted with things such as water and soil, houses and trees, rivers and mountains, but the air seems strange. We say "The air feels heavy" without quite thinking of heaviness as if we were lifting a piece of timber or a stone. We say "The air feels sticky, and I believe it will rain" without thinking of stickiness as if we were touching paste or glue. Why does the air feel heavy, and why does the air's stickiness suggest rain?

The air seems real enough when we use it to fill automobile tires or when we are caught out in a heavy windstorm. But when we see an aëroplane or a bird sailing through the air it is hard to realize that the aëroplane and the bird are supported by a real substance. Does the aëroplanist or the bird see the air? How do they know it is there? Can you tell by sight whether a drinking-glass is filled with water or is empty? Is an empty glass occupied by air? What do we mean by empty?

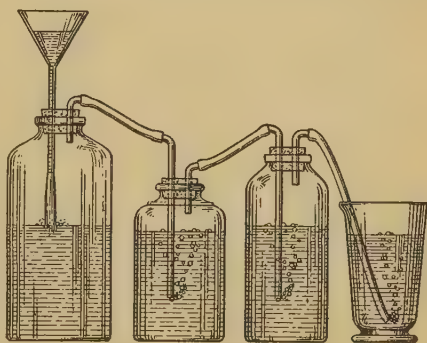


FIG. 2. When air is crowded

When water is poured into the funnel, what happens in each of the glass bottles and the cup?

11. Does air occupy space? There are a good

many experiments that may be performed to find whether air occupies space. We might, for instance, try to see whether a drinking-glass which is supposed to be filled with air can also be filled with water without displacing the air. In trying this we must be careful that the air cannot escape as the water enters, and the best way to do this is to invert the glass and put

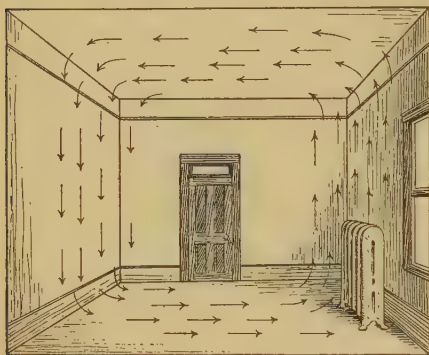


FIG. 3. The circulation of air

Diagrammatic representation of the circulation of air in a closed room heated by a radiator

it under water in this position, as shown in figure 1. It is found that the water does not fill the glass while the air remains in it. An experiment arranged as shown in figure 2 will make it possible to see what happens when the space containing a given amount of air is reduced. One may find an equally good problem by explaining the difficulty experienced in

pouring water from a narrow-necked bottle. Why is it that water will not pour in a steady stream from a narrow-necked bottle?

A football, a bicycle tire, an air cushion, and a pneumatic mattress when inflated present evidence that air occupies space.

12. Cold and warm air. If when the house is heated in winter time you have climbed upon a stepladder to fix a window shade or hang a picture, you may have noticed that the upper air of the room is warmer than that in the lower part of the room. Almost everyone has noticed rising currents of air over a radiator or stove. If the room is tightly closed, the movement of cold and warm air may be observed. The currents may be strong enough to carry light objects, such as bits of paper, and to cause pinwheels to revolve. When the air reaches the ceiling, it flows toward the more distant parts of the room,

and as it becomes cooler it may descend again (fig. 3). Its course may be easily traced if it is mingled with smoke. Less commonly we notice that air is flowing along the floor from all sides toward the source of heat (radiator or stove). One may find these bottom currents very easily if he will hold a burning match or candle near the floor in the vicinity of a heated stove or radiator, and note the direction in which the flame is blown. The air is always in circulation in a room in which there is a heated stove or radiator. Since the air in the vicinity of the source of heat is lighter, volume for volume, than that in the other parts of the room, it follows that the lower air near the stove does not have so much weight resting upon it as does that in other parts of the room. It is therefore pushed upward by the heavier, colder air round about and finally reaches the ceiling, when it spreads out, is cooled, and descends slowly in the cooler parts of the room; only to flow across the floor toward the source of heat, where it will again be warmed, expanded, and pushed up. Thus the circulation continues. Currents of air that are caused by differences of temperature, such as the currents of which we have been speaking, are called convection currents.

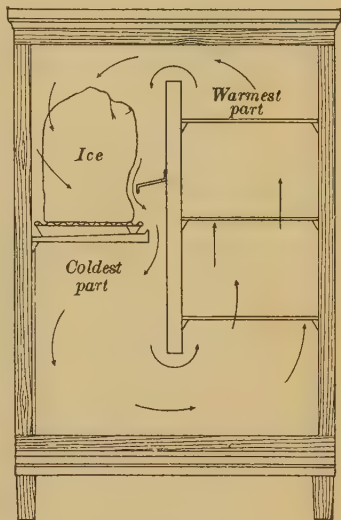


FIG. 4. Air currents in a refrigerator

13. Hot and cold air in a refrigerator. In the refrigerator shown in the diagram (fig. 4), advantage is taken of the fact that cold air is heavier than warm air. The ice, being placed in the upper part of the box, cools the air which comes in contact with it. This colder air flows downward and crowds up

the warmer air. In this way a constant current is maintained. This uses the same principle of convection currents to keep the refrigerator cold as is used to keep a living-room warm.

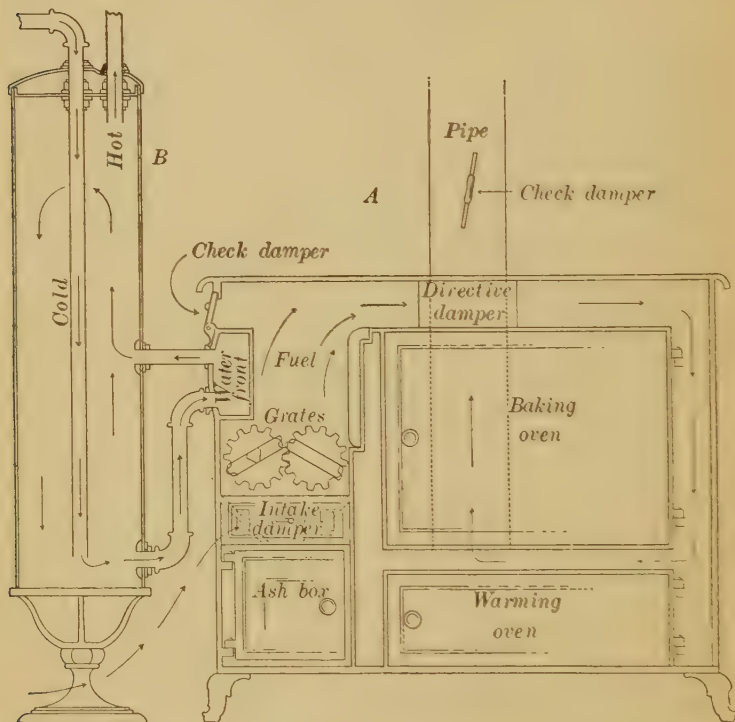


FIG. 5. Currents of air and water in a cookstove and water heater

Trace the air currents through the stove, and the water currents through the heater

14. Stoves, furnaces, and water heaters. The circulation of air in hot-air heating apparatus such as is commonly used in private houses is maintained by convection currents. The heater is located in the lowest part of the house, usually the basement, and is surrounded by a jacket which incloses a heating chamber. Cold air is admitted to this chamber from outdoors through a

large pipe. The air is expanded by heating, is pushed up through the pipes leading from the top of the air chamber to the various rooms of the house, and escapes out of doors through available openings. In some cases the apparatus is so arranged as to take cold air from within the house, as from the front hall, instead of from without. In the latter case the same air is passed through the rooms repeatedly, but fresh air from outdoors is desirable when proper heat can be maintained. The movements of hot and cold air and water are well shown in cookstoves and water heaters (figs. 5 and 6).

It will also be found of interest in this connection to determine the reason for the circulation of water in the hot-water pipes by which a building is heated.

15. Chimneys. The main purpose of a chimney is to supply a draft; that is, to cause the air to pass rapidly through the fire and make it burn more vigorously. The

chimney must also remove the smoke. Since the air in the chimney is heated, it is not so heavy as the outside air. The outside air therefore pushes through the furnace or fireplace into the chimney and crowds the warmer air upward, producing sufficient current to cause it to carry the smoke with it. The incoming cold air is heated as it passes through the fire, so that it is lighter than the outside air and is in turn forced upward. The movement of the air is therefore continuous.

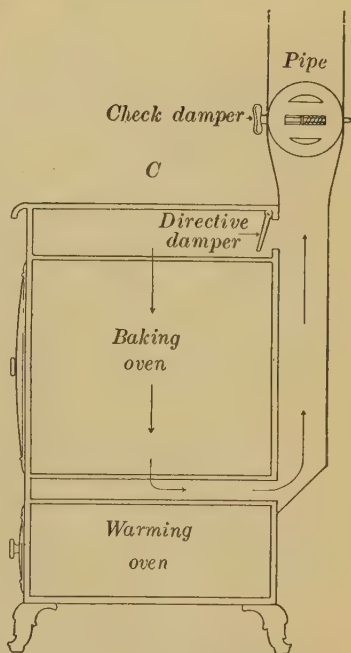


FIG. 6. Diagram showing end view of cookstove shown in figure 5

16. Importance of air temperature. The temperature of the air is a matter of importance to us all. It has much influence in determining whether our sports shall be tennis, golf, and baseball or coasting and snowballing; it decides for us whether



FIG. 7. An outside view of an old-fashioned chimney and fireplace

What causes the air to move through the fire and up through the chimney?

the water shall invite us to swim or to skate; it even settles pretty largely the kind of clothing we shall wear, the food we shall eat, and the social activities in which we shall engage. It levies a tax upon us for coal at one time and for ice and electric fans at another. Our whole round of activities in business and pleasure is very largely regulated by the temperature of the air and the seasonal changes. The more fully we understand air currents and the temperature of air, the more fully we shall be able to regulate these things to suit our needs.

17. Weight of air. We have spoken of colder air as heavier than hot air. How can we find what air weighs? The best way to find out is to weigh it as we should in finding out the weight of any other substance. A football or basketball may be secured and made as empty as possible, and then weighed. The weight

so secured is the weight of the ball and any air that is contained. If, now, considerable more air is pumped into the ball, a second weighing will show whether it causes an increase of weight.

A second method, which is more accurate, is as follows: The air (almost all of it) may be pumped from a brass globe or glass flask which is so constructed that it may be closed after the air has been removed.

The closed globe may then be placed upon a balance (fig. 8) and weighed. If the globe is opened (thus allowing air to enter it) and is again weighed, any difference in weight that is found will be due to the air which has come into the globe. If we suppose all the air

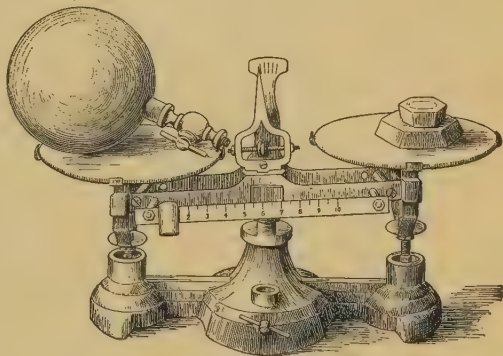


FIG. 8. Weighing the air

The globe, which was balanced after part of the air had been pumped from it, was found to be heavier when the air was again allowed to enter it

was pumped out, the increase in weight would be precisely the weight of the air the globe contains. Therefore we may measure the globe used and calculate the cubic contents, and thus find out the weight of the air per cubic foot or meter, as shown by the experiment. This result will not be quite correct, since not all the air can be removed from the globe by the pump, and therefore we include part of the air in both weights. Is our result greater or less than the true weight of air?

By attaching a barometer to the air pump it is possible to find out what fraction of the air was left in the vessel, and this enables us to tell exactly what relation the amount of air removed by the pump bears to the whole amount of air in the flask. By this means we may determine the necessary correc-

tions and discover the true weight of air. This has been done many times. Air varies in weight because of changes in temperature, moisture, and pressure, but at 32° F. it is about 34.5 grains per cubic foot or a little more than 1 pound per cubic yard.

18. Air pressure. If air has weight, it would be expected to press down upon the surface of the earth just as other bodies



FIG. 2. Air pressure.

When air is pumped from within the glass jar, the sheet of rubber is not over the opening and it lies in a shape downward by the weight, or pressure, of the outside air.

When the air is pumped from within the glass jar, the sheet of rubber is not over the opening and it lies in a shape downward by the weight, or pressure, of the outside air. It does not push the rubber downward, because the air within the glass resists, as it does in the bottom of the tin. If, however, the air is partially removed from the interior of the glass by the use of a pump, the resistance from within is reduced, and the rubber is pressed downward and may even be broken. It is upon this that there is pressure upon the upper side of the rubber, but that so long as the air was allowed to remain in the glass, the pressure upon the two sides was equal.

19. Compressibility of air. If a football is filled with air, it is sufficiently to keep it expanded and increased large, it is still possible to put more air into it. This is commonly done in filling automobile tires. In this respect air is quite different from other familiar substances. If a tire were filled with water, no more water could be put into it.

It is commonly known also, that a given body of air can be

do when they rest upon the earth: it would rest upon us and other objects on the earth's surface with considerable weight. The mass of this atmosphere may be varied. A siphon glass (fig. 2) may be placed upon the platform of an air pump, with a sheet of rubber tied over the opening. If there is any pressure upon the air, due to the weight of the air, it

compressed into a smaller space, as when one presses an air-filled toy ball between his hands. Most other familiar substances cannot be similarly compressed. Most people know also that as the amount of air in a tire is increased, the air pressure also increases. Indeed, it is for that reason that air is put into tires. The compressibility of air and the fact that air may exert pressure have long been known and used.

20. Working under water. In laying the foundations of bridge piers and of other structures which must rest below water level (fig. 10) it is common for the laborers to work in a large steel chamber which has no floor and which rests upon the bottom of the lake or river. This



FIG. 10. A lighthouse upon a submerged foundation

The foundation was constructed by men who worked under water

is called a caisson. The water is kept out of the caisson by the use of air pumps, which force air into it with sufficient pressure to overcome the pressure of the water. The entrance and exit of workmen without allowing the escape of the air in the caisson is made possible by means of a tubular passageway which leads to the bottom of the caisson.

When a workman wishes to enter the caisson, he first goes into the tube through an upper door, which is tightly closed after his entrance. Air is then forced into the tube or "air lock" until its pressure is equal to that in the caisson. He then opens the doors leading to the caisson, and enters, closing the doors behind him (fig. 11). When he emerges from the caisson the

process is reversed. In practice it is found necessary to allow a man to remain in the air lock for some time, while the air pressure is slowly increased or decreased, in order that he may not suffer from too sudden change of air pressure.

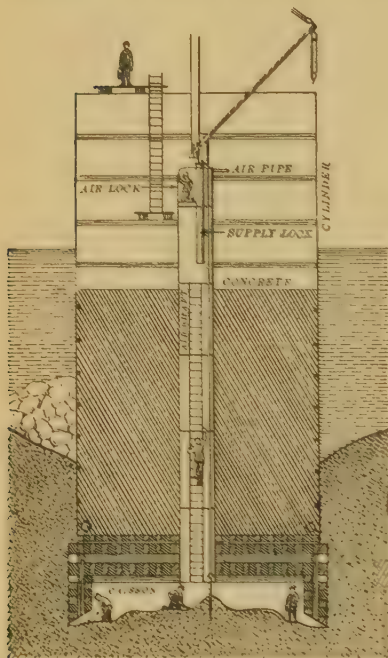


FIG. 11. Working under water

A diagram of the caisson used in sinking the foundation for the lighthouse. Note the men working in the air chamber below: also the men in different stages of passing into the air chamber through the air lock. After a drawing by the United States Bureau of Lighthouses

Compressed air is used also for excluding water in excavating tunnels beneath water level. The principles involved in excavating tunnels are similar to those of the caisson. Diving-bells are also used when men work under water. The use of compressed air in raising torpedoed ocean vessels gives promise of making it possible to regain immense quantities of lost property.

21. Some uses of compressed air. Automobile garages commonly keep compressed air stored in strong tanks and, when it is needed, place it in the tires through connecting tubes, or compression pumps are kept ready for use. The pumps used to inflate footballs and tires on bicycles or automobiles are devised to compress air rapidly and to force it into the tires.

The inexpensive pump shown in figure 12 can be used to compress air if the amount of compression needed is not large. If connection is made to the air inlet, the pump exhausts air in-

stead of pumping it into the tire. Most commercial air pumps are similar in principle to the one shown in the figure. Air

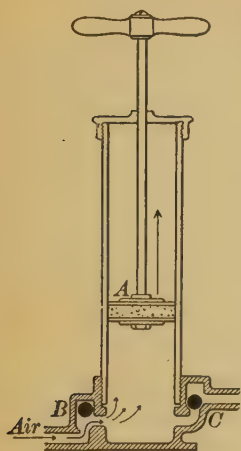


FIG. 12. Diagram of an air pump

When the piston *A* is pulled upward the valve at *C* closes and the one at *B* opens. What occurs when the piston is pushed downward?

pumps are common in garages, on railway cars, and on street and interurban cars. In railway and street cars compressed air is used in applying brakes. Everyone is familiar with the shrill noise made by the suddenly released air which has just been used in stopping the cars. Compressed air is also often used in blowing whistles and sirens, in operating the compressed-air engines, the heavy hammers used in construction work, and the drills used in blasting rock and coal, and for driving dentists' drills; and it is used in operating automatic devices for regulating the temperature in homes and in schools and other public buildings.

22. Measuring air pressure in tires.

In order to secure the proper air pressure in an automobile tire and at the same time to avoid danger of bursting it, there is need for a means of measuring the pressure and also need for knowledge of the amount of pressure which will make the tire give the best service. Pressure gauges (fig. 13) as measuring devices are in common use. Various types of these gauges are manufactured for a variety of different purposes.

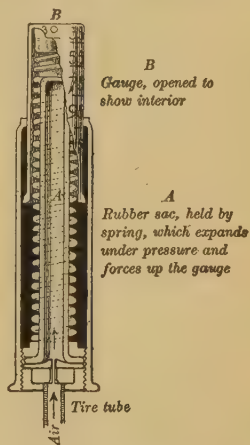


FIG. 13. Air-pressure gauge

By attaching this gauge to the air tube of an automobile or bicycle tire the amount of air pressure may be measured

The best service is secured by using automobile tires at the proper air pressure, and it is now customary to take the tire

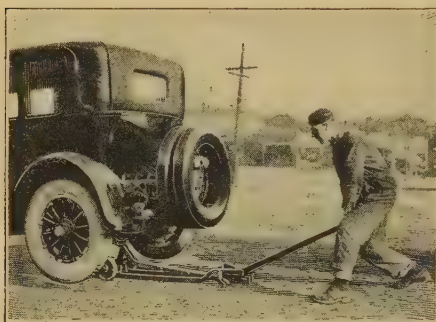


FIG. 14. A lifting jack

A powerful jack is needed to lift the weight that is ordinarily supported by air in the tubes

manufacturer's recommendations on this point. This information may be secured from the salesman. The weight of the machine and load to be carried (fig. 14) are considered in estimating the pressure, as is shown in the table, which gives the pressures recommended for some of the commonly used kinds of tires. It must be under-

stood that there are wide variations in the tire pressures recommended by the different tire manufacturers.

DIAMETER OF TIRE	PRESSURE PER SQUARE INCH	REAR LOAD PER TIRE AVERAGE CONDITIONS
3 in.	45 lb.	375 lb.
4 in.	60 lb.	750 lb.
5 in.	70 lb.	1225 lb.
6 in.	75 lb.	1710 lb.

23. Measurement of air pressure by barometers. Air pressure may be measured by use of instruments known as barometers. There are two principal types: the aneroid barometer and the mercurial barometer. In every community we now have daily weather reports which include statements of the atmospheric pressure. What does this mean?

The part of the aneroid barometer (fig. 15) which is sensitive to the air pressure is a small, thin-walled metal box that is shaped somewhat like the case of a watch. The air is exhausted from this metal box, which is sealed air-tight. The pressure of



FIG. 15. External view of an aneroid barometer

This type of barometer is graduated so as to show both the pressure and the elevation at which a reading is taken

the air tends to press the flat top and bottom of the metal box inward, as it did with the rubber top of the bladder glass, but the metal does not yield nearly so much as the rubber did. In fact the metal bends so little that it is not easy to see the change taking place. For this reason an arrangement of levers or gear wheels (fig. 16) which will magnify the motion is attached to the box and operates a pointer which moves up or down as the pressure increases or decreases. A still larger movement is secured in a compound barometer of

this type, which is constructed by placing six or eight of the metal boxes one above the other, as shown in figure 19.

The mercurial barometer is quite a different instrument. Indeed, at first it appears to have no resemblance to the aneroid. A simple mercurial barometer may be constructed in the following manner: Secure a glass tube about three feet long, with one end closed. Fill it with mercury, close the open end with the finger, invert the tube, and place the open

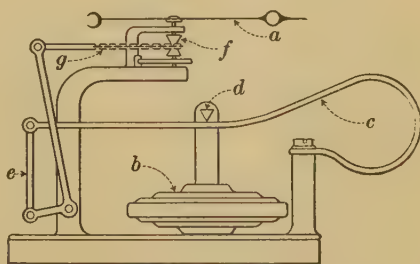


FIG. 16. The inner structure of an aneroid barometer

b, the vacuum chamber; *d*, knife-edge support for the spring *c*; *e*, the spring arm; *g*, a fine chain which winds about the pulley *f*, that operates the pointer *a*

end in a cup of mercury. When the finger is removed, the mercury will not continue to fill the whole tube but will fall so that the top of the mercury column is about thirty inches above the mercury in the dish (fig. 17). If this column of mercury is observed from time to time for several days, it will be found to rise or fall slowly. The change in height of the column is due to the change in pressure of the air.



FIG. 17. A simple barometer

The weight of the air supports the mercury in the glass tube. Any change in the weight of the air changes the height of the column of mercury

24. Graduation of the barometer. In order to be an efficient instrument a barometer must be graded into units so that it may be read. A scale of some kind must be attached to it in such a way that the movements of the pointer or of the top of the mercury column may be easily read and recorded (fig. 18). This scale might be marked in pounds pressure per square inch, and this would seem a very natural thing to do, but it is not the common method. Usually we express air pressure by stating the height of the column in a mercury barometer. These barometers are therefore graduated in inches or centimeters, and a scale of this sort will be found upon any practical instrument for measuring air pressure. An aneroid barometer is commonly given a scale so graduated that the numbers correspond with the readings of the mercury barometer, and therefore the readings of the two are alike. Mercury barometers were used long before aneroid barometers were devised. This accounts for the use of the system of measurement outlined above.

Some aneroids are so constructed that a pen attached to the pointer is caused to write on a piece of paper which is kept moving by means

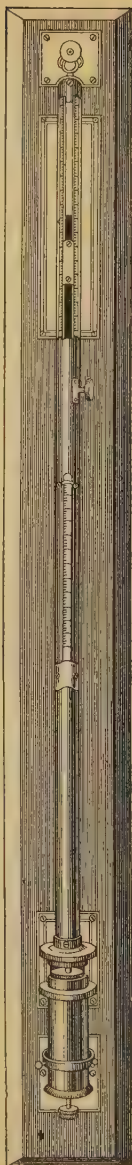
of a clock. In this manner a record of the readings is made. Such an instrument, called a barograph (fig. 19), is especially valuable because it makes a permanent record. A barograph record is shown in figure 20.

25. Altitude and air pressure. It was stated in sections 17 and 18 that the pressure of the air is due to the weight of the air above. It must be plain that if we ascend in a balloon, we are leaving some of the air below us, and the pressure of the air at our elevation will be less by a proportionate amount. If the bladder-glass experiment were conducted 1000 feet up in the air, as in a balloon, the rubber would be pressed down by a force equal to the weight of the air above it. There would be 1000 feet less depth of air above it than there would be if it were at the earth's surface, and the pressure would be correspondingly less. The same thing would be true on a mountain 1000 feet high, as has been noticed by those who have ascended mountains. It is this fact which makes it possible to use the barometer to measure altitudes (fig. 21). Since the air pressure decreases with increase of elevation, barometers may be graduated to read in terms of the elevation above sea level. Aneroids are frequently so graduated. Since their small size makes them convenient to carry, they may be used to learn the approximate height of mountains and the elevations reached by balloons or aëroplanes.

It is not possible to state any exact rule as to the pressure which will be found

FIG. 18. A standard barometer

A mercurial barometer with thermometer and scales. The graduations allow both barometer and thermometer to be read. This is the standard form of barometer used by the United States Weather Bureau



at any given altitude, but at elevations of less than a mile above sea level the pressure decreases an inch for each 900 to 1000 feet increase in altitude. The average pressures for various elevations are shown in the following table:

ELEVATION	PRESSURE	ELEVATION	PRESSURE
Sea level	30 inches	7010 feet	23 inches
910 feet	29 inches	8150 feet	22 inches
1850 feet	28 inches	9330 feet	21 inches
2820 feet	27 inches	10,550 feet	20 inches
3820 feet	26 inches	13,170 feet	18 inches
4850 feet	25 inches	16,000 feet	16 inches
5910 feet	24 inches		

Many persons when rapidly ascending or descending mountains experience an illustration of air pressure in their ears. The pressure in the inner ear is too great on going up or too small on going down, until the ear tubes open to admit air sufficient to adjust the pressures.

26. Effect of temperature. It is often noticed that a pneumatic tire which is only moderately firm in the morning when the bicycle or automobile is first taken upon the road may be much more firm by noon, as if more air had been put into it. The same thing will occur if the machine is allowed to stand in the sun. The additional pressure may, indeed, become so great as to burst the tire. It is very clear that no air has been added to that which was in the tire in the morning, for if the rubber will retain the air which is in the tire, it will be equally effective in preventing more from entering. Since such an increase of pressure occurs only when the tire has been heated by contact with the hot road, or by friction, or by direct exposure to the sun, it is fair to conclude that when the air is heated it has greater tendency to expand. It therefore presses harder against the walls of the tire and would expand if it were not confined by the tire. In other words, the tire is firmer, or more completely filled.

The notion that air expands when heated may be tested in many ways. For instance, an empty bottle may be inverted and

its mouth placed under water, and the bottle warmed by holding it between the hands or by use of a flame. The air will soon be warmed, and if it expands, bubbles of air will overflow from the mouth of the bottle and rise to the surface of the water. In what other ways can you test whether air expands when it is heated?

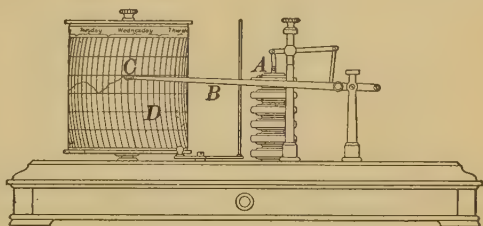


FIG. 19. Diagram of a barograph

27. Thermometers. Air expands when heated and contracts when cooled. It is possible to arrange apparatus in such

This instrument automatically records the air pressure. *A*, compound aneroid barometer; *B*, pointer, at the tip of which is *C*, the pen; *D*, paper-covered cylinder, which is rotated by a clock contained within it. As the pressure changes, the pen moves up or down, thus tracing its course upon the paper

a way that expansion and contraction may be observed and measured. An instrument by means of which such measurements could be made would give us some idea of the degree of

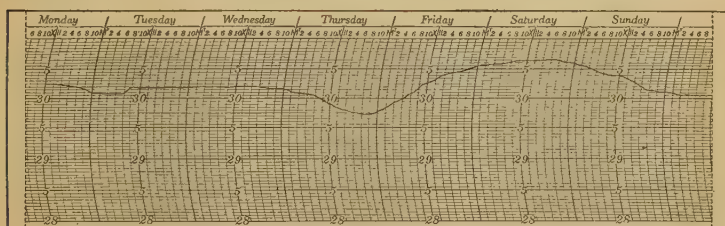


FIG. 20. A barograph record

Changes in atmospheric pressure in one week in January, 1924

heat. It would, in fact, be an air thermometer. Such thermometers have been constructed and used, but only for special purposes. For ordinary purposes much more satisfactory thermometers are made from other substances.

Thermometers such as are in common use depend upon the expansion and contraction of a liquid. The liquid most commonly used is mercury, though alcohol which has been colored red or blue is sometimes used. Each thermometer is furnished with a scale of degrees by means of which the temperature may be read. There are two kinds of scales in use in this country (fig. 22). The one in most common use is called the Fahrenheit



FIG. 21. Air pressures at different elevations

The illustration shows Mt. Rainier, Washington, from 5500 feet to the summit. The figures show the elevations at different points and the air pressures at these points. Note the decrease of air pressure with the increase of elevation

scale. On this scale the freezing point of water is 32° and the boiling point is 212° . The centigrade scale, which is the one used in all scientific work the world over, places the zero mark at the freezing point of water and the 100° mark at the boiling point of water. Because there are two scales, it is always necessary, when we write temperatures, to indicate which scale is used. Thus we say that the boiling point is 100° C. or 212° F. Since both types of thermometers are in use, it is important to be familiar with both of them and to be able to determine the equivalent of a given reading of one thermometer in terms of the other.

Since in the Fahrenheit scale the freezing temperature is 32° and the boiling temperature is 212° , therefore there are 180° between freezing and boiling, according to the Fahrenheit system. Since in the centigrade system the freezing temperature is zero and the boiling temperature is 100° , therefore 100 divisions on the centigrade scale equal 180 divisions on the Fahrenheit scale. One centigrade degree equals 1.8 Fahrenheit degrees. A temperature of 80° C. is equivalent to $80 \times 1.8 + 32$, or 176° F.

28. Some effects of expansion. It was learned in a previous experiment that if the air in a bottle is heated, the mouth of the bottle remaining open, the air will expand and some of it will escape. The air that remains fills all the space that the whole amount originally occupied, but plainly it cannot weigh the same, for only a part of the original air is in the bottle, and a part cannot weigh as much as the whole. Careful measurement and weighing will show that the weight of the bottle is less by exactly the weight of the air which has escaped. We usually express this by saying that heated air is lighter than cold air. We must remember, however, that this is true only under certain conditions. For instance, if we put a stopper in the bottle so that there can be no expansion and therefore no escape of air, after heating the bottle we shall have all the air that was in it at first, and it will weigh exactly the same. As stated before, if we allow the bottle to remain open, at the second weighing we shall be weighing only a part of the air that we had at the first, and hence the weight will be less. It would be better to say that heated air is lighter than cool air if we take equal volumes under the same pressure.

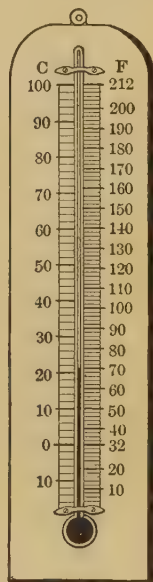


FIG. 22. A mercurial thermometer

Both Fahrenheit and centigrade scales are shown

CHAPTER III

AIR AND WATER

29. Questions for discussion. 1. Why do clothes usually dry better on warm days than on cold days? 2. Will clothes dry as rapidly on a very cold dry day as on a very hot dry day? 3. Which can endure the higher temperature, the man who perspires a great deal or the one who perspires but little? 4. Water sometimes collects on cold-water pipes on summer days, while on other days the pipes are quite dry. Why? 5. Why does water appear upon the pipes most abundantly when cold water is running through them?

6. Why are grass and other plants often moist in the morning although no rain has recently fallen? 7. Why does frost form on windows in winter? 8. What are the conditions necessary to the deposit of dew? 9. How does the practice of flooding cranberry bogs help to protect the cranberries against frost? 10. Do snow and ice evaporate during cold winter weather?

30. Evaporation. It is a matter of common observation that water left exposed to the air may soon disappear. We say that it has evaporated. It has not gone out of existence, but has changed into a form in which it is invisible. It has become a gas and has passed into the air. There is usually considerable water in the atmosphere, and so long as it remains in the form of a gas (water vapor) it is invisible, just as is true of the remainder of the atmosphere. We are made very uncomfortable when the amount of water vapor in the air is either extremely small or extremely large. Why?

31. Condensation. It is a common observation that if a glass pitcher which has been carefully dried on the outside be filled with ice water, the outside of the pitcher may soon become moist. Sometimes the amount of water so condensed is sufficient to wet the tablecloth almost as if water had been poured

upon it. Thoughtless persons have sometimes accounted for the phenomenon by supposing that by some means water has got out of the pitcher to the outside. A little reflection shows that this cannot be the explanation, since the same thing will occur to a cold and solid piece of metal if it is brought into the room. Also, those who wear eyeglasses are annoyed by the moisture which collects on their glasses when they go from cold air out of doors into warm living-rooms. Indeed, if the ice water were inclosed within a tightly stoppered bottle instead of being



FIG. 23. Drops of water collected upon a spider web

When the night air is quite moist, drops of water frequently collect upon all sorts of solid objects

exposed to the air in an open pitcher, the collection of moisture would not be stopped. Out of doors, at night, water sometimes collects on solid objects, and sometimes the air itself becomes filled with a fog which consists of minute floating particles of water (fig. 23). All these things may occur quite independently of any visible source of water, such as a pond or lake.

It must be clear that the water which appears upon cold objects comes from the air, just as the water which evaporates goes into the air. We may conclude also, since it appears or condenses only upon objects relatively cooler than the air, that the temperature is partly the cause. These conclusions, even if

verified by other experiments, do not solve all the problems connected with the deposit of water on the pitcher. Why is not water always condensed upon the outside of vessels containing ice water? Is there at such times too little water in the air, or is it because the temperature of the surface and of the air is too nearly the same?

32. Amount of water in the atmosphere. If all the moisture in the atmosphere of the earth were condensed into liquid water, it is estimated that it would make a layer at least an inch deep over the whole surface of the earth. The amount of water in the atmosphere in the form of vapor varies greatly at different times and places. The amount of water in the air is an important factor in producing cloudy and clear days, rain, dew, fog, snow, and the discomfort that we have upon warm, "muggy" days in summer.

An experiment or illustration will help to show what controls the amount of water vapor present in the atmosphere. Suppose that a small quantity of water is placed in a dish within an air-tight chamber. The water will immediately begin to evaporate, but it will not all evaporate. The space in the chamber will soon contain all the water vapor that it is able to contain under existing conditions, and evaporation will then cease. The space within the dish is said to be saturated with water vapor when it contains all that it is able to contain. If the dish is warmed, however, an additional amount of water will evaporate; while if it is cooled, some of the water vapor will return to the liquid form and may be seen upon the inside walls in the form of drops.

It is thus seen that the water evaporates into the adjacent space until the space is saturated and that the amount of water which is needed to saturate a given amount of space depends upon the temperature. The exact amounts of water in grams per cubic meter of saturated space are given for reference in the table in section 34. This table is for inspection and reference, but it will not be found profitable to attempt to remember the figures given.

33. Moist and dry air. The air about us is not often saturated with water vapor. Among the reasons for this may be mentioned the fact that in many parts of the world there is not much water exposed and therefore not much opportunity for water to evaporate. Even where there is much water exposed, as at the surface of lakes and oceans, the space above the water is not usually saturated, though it may contain a large amount of water. For instance, a space today may contain half as much moisture as would be possible at the present temperature, while tomorrow it may contain only a third as much as would be needed to saturate it without changing temperature; that is, in the first case the space may be said to be one-half saturated and in the second case one-third saturated. These relations are usually expressed in percentages. When saturated, the space contains 100 per cent of the moisture that it is able to contain without change of temperature; if only half the possible amount is present, the percentage is 50; and similarly for other values. This percentage expresses the relation between the water actually present and the amount which the space would be able to contain at the temperature given. This relation is called the relative humidity.

The amount of water which is actually present in a given space is known as its absolute humidity and may be measured in grams per cubic meter. Absolute humidity therefore refers to the amount of water actually in the air, and relative humidity refers to the relation between the amount of water actually contained and the total amount which might be contained at the same temperature.

34. Reference table of the amount of water in one cubic meter of saturated air at given temperatures. In this table the temperatures are given in both centigrade and Fahrenheit degrees. In this and succeeding work students should practice thinking in both systems of temperature measurements, since the Fahrenheit system is in common public use, and the centigrade system is in general use in science and likely to become more common in public use.

Relative humidity can be 100 per cent only when the amount of water actually in the air is the full amount that the air can contain at that temperature. For example, a cubic meter of air at 16° centigrade (60.8° F.) might contain 13.50 grams of water. If we find that it actually does contain 6.75 grams (absolute humidity), it has one half, or 50 per cent (relative humidity), of the amount of water it might contain when fully saturated at that temperature.

TEMPERATURE		AMOUNT OF WATER IN GRAMS	TEMPERATURE		AMOUNT OF WATER IN GRAMS
C.	F.		C.	F.	
0°	32°	4.84	20°	68.0°	17.12
1°	33.8°	5.18	21°	69.8°	18.14
2°	35.6°	5.54	22°	71.6°	19.22
3°	37.4°	5.92	23°	73.4°	20.35
4°	39.2°	6.33	24°	75.2°	21.54
5°	41.0°	6.76	25°	77.0°	22.80
6°	42.8°	7.22	26°	78.8°	24.11
7°	44.6°	7.70	27°	80.6°	25.49
8°	46.4°	8.21	28°	82.4°	26.93
9°	48.2°	8.76	29°	84.2°	28.45
10°	50.0°	9.33	30°	86.0°	30.04
11°	51.8°	9.93	31°	87.8°	31.70
12°	53.6°	10.57	32°	89.6°	33.45
13°	55.4°	11.25	33°	91.4°	35.27
14°	57.2°	11.96	34°	93.2°	37.18
15°	59.0°	12.71	35°	95.0°	39.18
16°	60.8°	13.50	36°	96.8°	41.30
17°	62.6°	14.34	37°	98.6°	43.50
18°	64.4°	15.22	38°	100.4°	45.80
19°	66.2°	16.14			

The relative humidity of the air over the surface of the earth varies widely. The relative humidity over the land in the Eastern states averages about 60 per cent, and over the ocean it averages about 85 per cent. But variations from these averages are so great that the averages do not tell us much about any given day or given locality. If the relative humid-

ity is low, we say the air is dry; if the relative humidity is high, we say the air is moist or "muggy" or "sticky."

35. Saturation and the dew point. If the temperature falls below that at which the contained vapor saturates the space, some of the water will condense into the liquid form. If the



FIG. 24. Moisture condensed as sleet
by a sudden drop in temperature

Note branches broken by the weight of ice

temperature falls below the freezing point, moisture may be deposited in the form of snow or sleet (fig. 24).

If the space in a room is at a temperature of 22°C . (71.6°F .), and contains 10 grams of water vapor to the cubic meter, the air will appear rather dry, for it would be able to contain over 9 grams more without being fully saturated. If, however, the room were cooled to 5°C . (41°F .), its capacity would be decreased to less than 7 grams per cubic meter. Some of the water would therefore condense into

the liquid form and settle upon surrounding objects. In the case supposed how much would condense? (See the table in section 34.)

The temperature at which a given space will be saturated by the water that it contains and below which the water will begin to condense is called the dew point. What was the dew point in the above example?

In the example used above, when the air was at the temperature of 22°C . and there were 10 grams of water per cubic

meter, what part did the room actually contain of the total amount that it was able to contain at that temperature? Express your result in the form of a fraction; also in the form of a percentage.¹ Is this relative humidity or absolute humidity? If the room contained all the water that it could contain without a change in temperature, what would be the relative humidity? What is the relative humidity at the dew point?



FIG. 25. Cumulus clouds

This kind of cloud is formed by the condensation of moisture in columns of rising air. Note the characteristic lower edge of the cloud, indicating the level at which the dew point is reached

Relative humidity is of much more interest to us than absolute humidity. Whether the atmosphere feels dry or moist or whether clouds are seen (fig. 25) depends upon what proportion the air has of the water that it is able to contain (that is to say, upon how near the relative humidity is to 100 per cent). We are much more concerned with the way the atmosphere feels and the probability of moisture condensing in the form of rain than we are with the number of grams of water in a cubic meter.

¹There is a slight error in this method, since no allowance is made for contraction due to cooling. Exact work would require that the proper correction be applied, but the error is so slight that it is immaterial for present purposes.

36. How to determine whether the air is moist or dry. If you wish to know whether the air of your room or the air out of doors is relatively moist or dry, you may form some opinion by noting whether the air feels moist or dry; but opinions are inaccurate. Again, one may use the ice-water pitcher, and this will give more accurate information. If the air contains relatively large amounts of water, the condensation upon the pitcher will be more abundant and will appear more quickly after placing the water in the pitcher than would be true in a dry atmosphere. Thus one may be able to estimate roughly the relative moisture of the air and the consequent probability of rain.

If more accurate information regarding the relative moisture of the air is desired, in order that it may be expressed in figures for record or comparison, a more carefully designed experiment is necessary. In the previous statements about absolute and relative humidity the figures used had been previously determined. If we wish to know the relative humidity of a school-room or room at home, we shall need to find both absolute and relative humidity.

An experimental method for learning the amount of water in the air is as follows: Water is placed in a bright metal cup, ice is added, and the whole is stirred in order that the water may be evenly cooled. In a short time water will be deposited on the outer surface of the cup in a thin film, and as time passes it may accumulate in drops, as it does more familiarly on a pitcher containing ice water. This water has been deposited from the air because the space about the cup is cooled by the cold metal until its capacity for water vapor is less than the amount of such vapor present. Some of the water vapor therefore condenses into the liquid form and is seen on the surface of the cup. At the moment when the first trace of moisture appears upon the surface of the cup the adjacent space is evidently saturated; that is, the temperature close to the cup is that at which the water vapor present saturates the space.

We know now the temperature, which for illustration we will suppose is 10°C . (50°F .), to which this particular body of air

or any part of it would all need to be cooled in order for it to be at the saturation point. By reference to the table in section 34 we find that at this temperature saturated air contains 9.33 grams of water per cubic meter. This, then, is the absolute humidity of the room. However, the room thermometer shows the room temperature to be 20°C . (68°F .), and our table (Sect. 34) shows that air at this latter temperature when

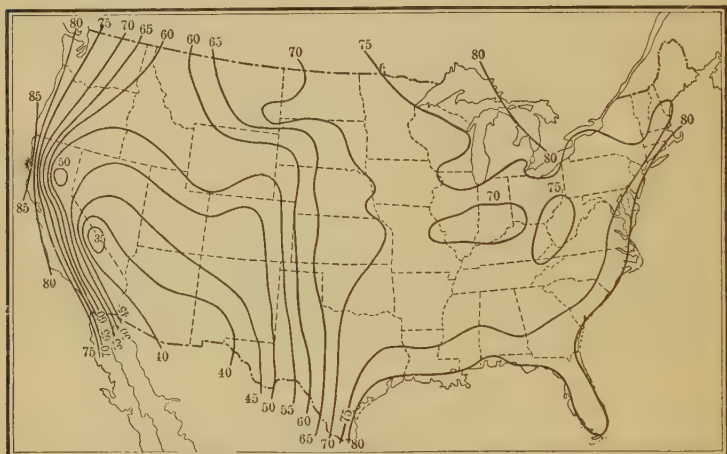


FIG. 26. Average relative humidity in the United States

The figures show relative humidity in percentages. After diagram by H. J. Cox

saturated contains 17.12 grams of water per cubic meter. Therefore we need to determine what per cent 9.33 is of 17.12. It is 54.49 per cent, so 54.49 per cent is the relative humidity of the air. By use of this method it is possible to determine with approximate accuracy the humidity of any room or of the open air at any time.

37. Variations in relative humidity. As noted before, if the temperature changes, the relative humidity changes also. For instance, a space which is saturated at one temperature may have its relative humidity reduced very greatly by a temperature increase of a comparatively few degrees. In the same way

the relative humidity changes during the day as the temperature rises and falls. It also changes because of changes in the actual amount of water present — absolute humidity. In most parts of the United States (fig. 26) other than in deserts, the relative humidity in summer averages not less than 65 per cent; in the desert region of the Southwest it may average below 30 per cent; and there is a record of relative humidity as low as 3 per cent at Yuma, Arizona, though this very low humidity at the time when recorded did not last more than a few hours.

The results of changes in relative humidity may be observed in connection with fogs. In a region where the air usually contains considerable moisture the fall of temperature at night may cool the air below the saturation point. In that case a part of the water in the air condenses in the form of small drops which remain suspended in the air. This is fog. When the sun rises, the air is warmed; and when the temperature rises above the saturation point, the drops of water evaporate and the fog is gone. During all these changes in relative humidity the actual amount of water in the air (absolute humidity) may have remained the same.

The relative humidity of the air is of very great practical importance. In regions where the relative humidity is usually very low the dry air evaporates water so rapidly that many kinds of crops can be grown only with the greatest difficulty or not at all; but such an atmosphere is less trying to men than is the almost saturated air of some tropical regions.

CHAPTER IV

THE WEATHER

38. Questions for discussion. 1. Of what value are weather reports to a farmer or gardener? to a shipper? to your neighborhood? to the United States? 2. Why is the air usually invigorating after a severe thunderstorm? 3. Is there pressure of the air against your face when the wind blows? 4. How are low air pressures and high air pressures related to winds? 5. What is a cyclone? a tornado? a storm? 6. Why is it that in a tornado trees, houses, and other objects instead of being blown ahead of or out from the storm center are drawn toward it?

7. How do fishermen generally judge whether a storm is coming? 8. What causes the hot waves which sometimes sweep over great stretches of the Mississippi Valley? 9. What is the source of the water which falls as rain? 10. What is the supposed relation between forests and rainfall? 11. By study of the rainfall map of the United States determine whether there is any relation between the regions of the greatest rainfall and the regions of greatest crop production. 12. Is it of any importance to crops whether the rainfall occurs chiefly in a given part of the year or is distributed over the entire year?

13. How does the United States Weather Bureau determine the amount of rainfall throughout the year in different parts of the country? 14. Is snow counted as part of the rainfall? 15. How is its amount measured? 16. In your locality what are the months of greatest rainfall? 17. Are these the months in which vegetation makes most growth?

39. Weather signs. "Shall we take an umbrella?" or "Do you think it will rain?" are questions asked by people wherever umbrellas exist and whenever rainfall might interfere with pleasure. No matter how keenly we may desire to have rain for growing field crops or for park flowers, not many people really enjoy being in the rain unless they are well protected (fig. 27). Rainfall and other features of the weather have long been recognized as highly important in connection with the

things which people may wish to do. In primitive times, and even today, weather signs are numerous in folklore. Some of these signs are the results of years of observation and experience, while others are only the crudest superstition. It is only



FIG. 27. An umbrella day

When the United States soldiers of the Civil War were gathered in London, England, to observe the unveiling of the Saint-Gaudens statue of Lincoln, the exercises were held in spite of a constant fall of rain. Photograph by the Keystone View Company

in recent times that men have secured anything like a true knowledge of the causes of changing weather, and the answers to many problems are still unknown (fig. 28).

We now know that we have rain when there is cause for rain, and that the wind's blowing this way or that depends not upon mere chance but upon certain definite causes. We can discover and understand some of the causes connected with the weather. By so doing, what seems chance or mystery will be made clear, and probably we may become able to foretell the weather for

the immediate future. It is not likely that any except specially trained students of the weather will be able to foretell weather conditions for two or three days in advance. Men have not yet been able to discover all the causes which are at work in the production of our weather, but enough have been discovered to make the science of meteorology one of great importance.



FIG. 28. Reading the weather in the sunset clouds

When one knows the prevailing winds and has learned to follow the changes in air pressure, he can judge whether clouds such as these mean that changes in weather are ahead

40. Causes of winds. Most other features of the weather depend upon currents of air which we call winds. Winds are merely air in motion, and the faster the motion the harder the wind is said to blow and the more it affects the things which are in its path.

To explain the causes of winds we must return to the subject of air pressure and barometers. Anyone who has observed a barometer at periods over several days knows that its indicator goes up and down. This shows that the air pressure is con-

stantly changing. The records or readings of barometers at a great many places in the United States are not the same, even though these records are all made at the same time. The readings show that in some parts of the country the pressure is high, while in others it is low. We might find, for instance, that the barometers read 29.8 inches in Iowa but only 29.5 inches in Indiana. The records show that the pressure is never the same all over the country and that it does not long remain stationary at any one place. The most unchanged thing seems to be the fact that the pressure is always changing.

If the pressure of the air is high in Iowa and relatively low in Indiana, we can see that the air next to the ground in Iowa will tend to flow toward places of less pressure. It will move from Iowa toward Indiana across the intervening state of Illinois, and Illinois will therefore have a wind from the west. If the difference of air pressure between Iowa and Indiana were only 0.1 inch, the wind would be very light; if the difference were as much as 0.5 inch, the wind which results would be very strong. These constant differences in pressure between the various parts of the country are constantly causing mild or strong winds; that is, the air is always flowing from regions of high pressure to regions of low pressure.

41. Weather maps. A good idea of the distribution of high and low pressures (figs. 29, 30, and 31) throughout the country may be obtained by looking at a weather map. The air pressures are represented on the maps by heavy black lines. These lines are drawn in such a way that all places which have the same air pressure are shown on one line. The figure which represents this pressure is marked upon the map close to the line. These lines connecting regions of the same air pressure are called isobars. This word really means "equal weight," but it is used to refer to regions which have similar air pressures.

The weather map is made in the following manner: Each morning at eight o'clock (Washington time), at every weather-bureau station in the United States, the barometer is read, and the reading is immediately telegraphed to Washington. The

readings thus collected are placed upon a map, each at the location of the city from which it was telegraphed. The lines are then drawn through places having the same pressures. These lines thus make it possible to see very easily where the high-pressure and low-pressure centers are located. Usually a map will show several well-defined areas of this kind.

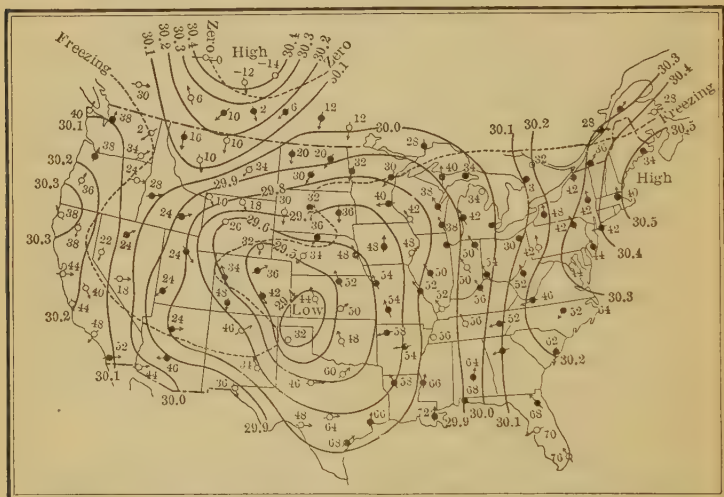


FIG. 29. Weather map for a March day

The three maps for successive days (figs. 29, 30, and 31) should be compared to show the progress of the storm and the changes in weather conditions. The unbroken lines are the isobars; the arrows fly with the wind; the blackened circles indicate cloudy weather at the time of observation; the figures near the arrows show temperature; one broken line passes through places of freezing temperature; the other connects points with zero temperature. These figures are from the United States Weather Bureau

42. Movement of high and low pressures. As soon as the map is finished the meteorologist may make comparisons with maps for preceding days. In this way he can see what weather changes are occurring. He can also foretell what is likely to occur on the next day. Observation of maps on successive days will disclose the fact that a "low" moves eastward across the

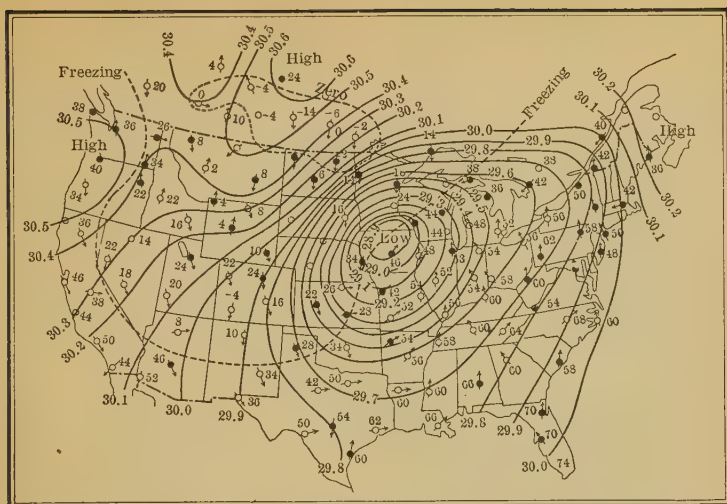


FIG. 30. Weather map for March day following that shown in figure 29

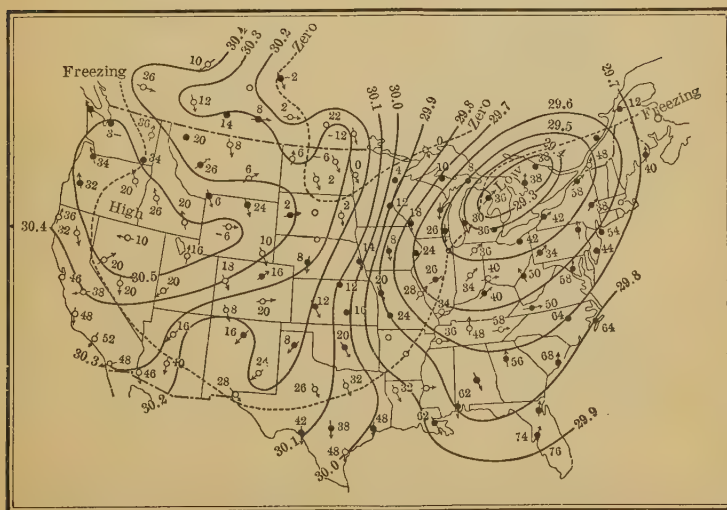


FIG. 31. Weather map for the March day following that shown in figure 30

country at the rate of several hundred miles per day. Often several of the "lows" may be on the map on the same day. The centers of the "lows" commonly cross the northern part of the United States or the southern part of Canada and almost invariably pass through the St. Lawrence River valley. The "highs" occupy the spaces between the "lows." They also proceed eastward across the continent, but their course is usually inclined toward the southeast, and their progress is not so regular as that of the "lows." Both "highs" and "lows" are commonly elongated in a north-and-south direction and are often compared to a series of great waves in which the "highs" are the crests and the "lows" the troughs.

43. Winds about a "low"—cyclones. Since a low area usually has a more or less circular form and is surrounded by higher pressures, it follows that the air will tend to flow into the low area from all sides. If there were nothing to direct the course of the wind except its tendency to blow toward the lowest pressure, it would blow from all directions straight across the isobars toward the center of low pressure. An examination of the weather maps, in which the wind direction is indicated by arrows, shows that while the wind blows into the low areas, it does not blow straight toward the center of the "low." Instead, the air turns a little to its right (fig. 30). That is, at a point north of the "low" the air is moving not south but southwestward; at a point east of the "low" it may be moving northwest instead of west; and so likewise for other places in the vicinity of the "low."

This deviation of the wind from the expected direction is due to the rotation of the earth on its axis. The rotation does not cause the wind to blow, but it does affect its direction. The effect of rotation upon moving bodies may be illustrated by pouring water upon a rotating globe. Water is heavier than air and consequently does not act exactly as air. However, the effect of the earth's rotation may be illustrated by use of water. If a smooth-surfaced globe is placed with the pole which represents the north pole of the earth pointing upward, and rotated

while the water is poured upon it, the water-marks on the surface of the globe will not run directly from pole to pole, like meridians, but will be curved to right or left (fig. 32). If the globe is rotated in the same direction as the earth is rotating, the paths of the water will curve to the right (westward) in the northern hemisphere, but as soon as the drops cross the equator they begin to curve to the left (eastward). Precisely the same thing occurs on the surface of the earth. It is a general law that anything moving on the surface of the earth will tend to follow a curving path. In the northern hemisphere this path curves or is turned to the right. Therefore the direction of the rotation of cyclones and other storms is opposite to the direction which is followed by the hands of a clock, or counterclockwise. In the southern hemisphere the deflection is to the left, and the rotation of storms is therefore clockwise.

There are at least two factors controlling the movement of the wind: the differences of pressure, which cause the air to move across the isobars toward places of lower pressure; and the rotation of the earth, which deflects the moving air to the right of the course which it would otherwise follow. Since the effect of the earth's rotation is the same, regardless of whether the

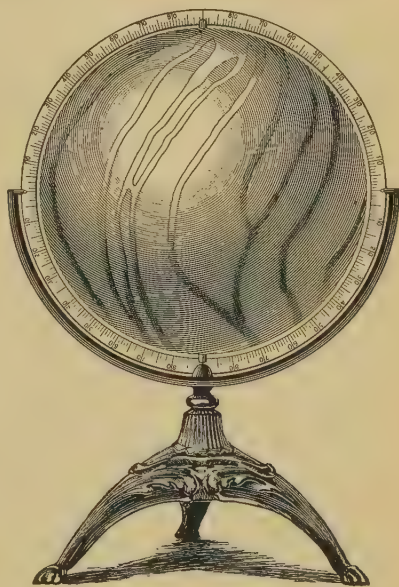


FIG. 32. Deflection on a rotating globe

Water was poured upon the top of the globe while it was rotating from left to right. The direction of the water is reversed after crossing the equator

air is moving east, west, north, south, or in some intermediate direction, the air about a "low" will circle about it before reaching the center. Each mass of air will travel in a spiral direction, and the whole body of air about the "low" will rotate. The action of the air is like that of water when it is running through a hole in the bottom of the vessel containing it. We must therefore think of a "low" as a great whirlpool of air, sometimes as much as a thousand miles in diameter and moving slowly eastward. Such a great spiral whirl is called a cyclone. The cyclone must not be confused with a very destructive storm which occasionally occurs and which is incorrectly called a cyclone. The proper name for the local spiral destructive storm is tornado. The air about a "high" is deflected to the right and thus circulates spirally outward (fig. 34). This is called an anticyclone.

44. Temperature in a cyclone. When warm winds blow to a cooler part of the country they cause it to become warmer, as when a south wind blows over the Northern states and produces higher temperature. Likewise a wind from the cold plains of the Northwest in winter may carry a freezing temperature all the way to the Gulf coast. Since the winds come into a cyclone from all directions, it follows that there must be parts of it in which cool air is going southward and cooling warmer places, and other parts of the storm in which warm air from the south is carrying warm weather northward. Let us consider as illustration the case of the warm air from the south and its effects on temperatures in the cyclone. If we refer to the weather maps (figs. 29, 30, and 31), we see that the spiral course of the air which comes into the "low" from the south carries it a little to the east of the center of the "low." Therefore the eastern part of the storm will have southerly and warm winds. The western part, on the contrary, will have wind which is coming from the north or northwest and is comparatively cool. We may therefore expect to find that the temperature rises as a "low" approaches any given region, and falls as it passes. On weather maps places of equal temperature are connected by dotted lines, just as places of equal pressure are connected by

continuous lines. The lines representing equal temperature are called isotherms, meaning "equal heat."

45. Humidity in a cyclone. We are probably as much concerned about the moisture in the air and about clouds and rain as we are about the wind or temperature. In a previous chapter we learned that the relative humidity varies when the temperature varies. Air which appears moderately dry when hot may appear to be very moist when cooled, and some of the moisture may condense. When air from the south is moving northward and warming the country over which it passes, it is itself losing heat and becoming cooler. As it becomes cooler its relative humidity becomes greater, until finally saturation may be reached, and the condensed moisture may appear in the form of clouds. If condensation of the moisture within the

cloud continues further, the moisture will fall in the form of rain, or under certain conditions it may fall in the form of snow or hail.

As pointed out before (Sect. 43), the warm southern winds are blowing northward in the front part of the storm (the eastern half) and are being cooled, and it is here that clouds and rain are found. In the western half of the storm the winds are coming from northern and cooler places and are being warmed. Capacity for moisture is increasing, and there is no condensa-



FIG. 33. Tree overturned by the wind

How could the wind push hard enough to upset the tree?

tion in this part of the storm area. The air in the western part of a cyclone is usually clear, dry, and relatively cool.

Large bodies of water and great irregularities of the earth's surface, such as mountain ranges, may cause extensive local variations in the character of the weather which accompanies the passage of cyclones.

46. Movement of a cyclone. Several cyclones usually pass eastward over the United States each week. Cyclones and anticyclones commonly follow so closely upon one another that we are practically always in one or the other. Most of the winds which we experience are cyclonic winds. Likewise most of the rainfall in the central parts of the United States is produced by these winds. The events that occur in connection with the passage of a cyclone have been described as follows in a pamphlet issued by the United States Weather Bureau:

When the wind sets in from points between south and southeast, and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or to the north of the observer within twelve to twenty-four hours, with winds shifting to northwest by way of southwest and west. When the wind sets in from points between east and northeast, and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within twelve to twenty-four hours, with winds shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and amount of the fall in the barometer.

47. Weather in anticyclones. The air which flows into a cyclone usually rises when it reaches the center of the storm. In this way the circulation is maintained. An anticyclone is an area in which the cooler air of the upper regions is settling to the surface of the earth and flowing away in all directions. Since this air at the surface of the earth has come from the cooler regions above, it is getting warmer, and as it flows away from the center of the "high" most of it is still going to warmer regions. Since it is becoming warmer and is expanding, it is

relatively dry. For these reasons the weather in a region covered by a high-pressure area is usually cool, clear, and dry, with a west or northwest wind. Most of us have noticed the bracing air of the pleasant days which follow a period of clouds and rain. This is typical anticyclone weather.

48. Hot and cold waves. A large low-pressure area sometimes draws much air from the south into the northern part of the

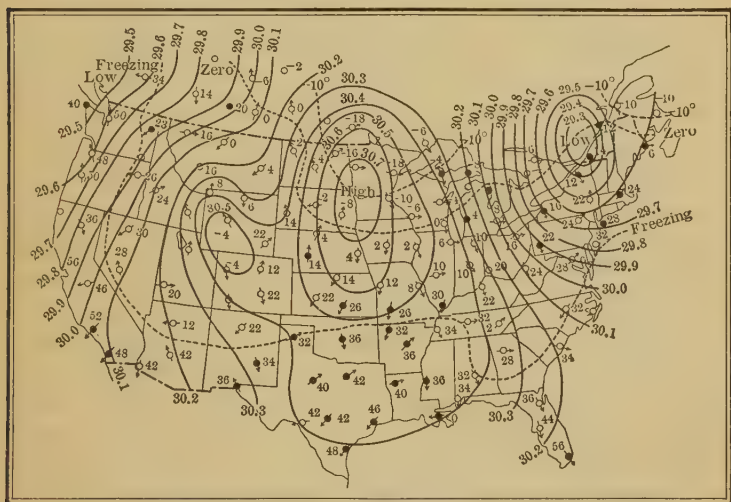


FIG. 34. An unusually large "high" pressure area in January

Note the low temperatures throughout the country. (United States weather map)

country. The temperature of the north thus rises unseasonably high, producing a period of very warm weather, usually called a hot wave, or a sirocco. In the western part of the Mississippi Valley the crops are sometimes seriously damaged by hot winds, or siroccos, coming from the deserts of the southwestern part of the United States.

If a high-pressure area remains for a while in the Northwest, the cold air which comes from it may spread over the greater part of the country (fig. 34); and if the fall in temperature is

rapid and of considerable amount, it is called a cold wave. The presence of low pressure over the Gulf of Mexico or over the Atlantic Ocean near our southern coast will usually assist in the progress of the cold wave. Freezing temperatures may reach the Gulf coast and at rare periods extend down the Florida peninsula. In such cases there is great loss resulting from the freezing of orange trees and the crops of early vegetables. On the great plains of the West and Northwest the cold wave may be accompanied by a strong wind and considerable driving snow. In this case it is called a blizzard. It sometimes happens that people who are caught in a blizzard are unable to find their way home and are frozen to death. Cattle and other live stock sometimes perish in the blizzards.

49. Hurricanes. Hurricanes are storms of the same general character as cyclones, but they originate only over the oceans. Those which affect the United States usually have their origin near the West Indies. They ordinarily move westward toward the coast of the southern United States and then gradually curve northward and northeastward and pass out over the Atlantic Ocean with decreasing severity. It is common for them to pass almost parallel to our eastern coast and to do a great deal of damage to shipping. Occasionally one of them goes far enough westward in its earliest stages to enter the Gulf of Mexico. In the year 1900 the city of Galveston was severely damaged by a hurricane which had taken this unusual course (fig. 35).

These storms are of very much greater severity than the cyclones. They do a great deal of damage in the West Indies and occasionally upon the mainland.

50. Thunderstorms. In the warmer parts of the year the layers of air next to the surface of the earth may become much warmer than the air higher up, and this difference may become so great that the lower layers are distinctly lighter than the upper layers. If this is the case, the lower air begins to rise through the upper air in ascending currents somewhat like the ascending currents of air over a heated stove. At a height of several thousand feet the ascending air may be sufficiently

cooled to cause the condensation of some of the water and the formation of the dome-shaped white cumulus clouds which are such familiar objects in summer time.

If the conditions are such as to cause very vigorous movements of the air, and if there is a good deal of moisture in the lower air, the clouds may grow until they become heavy and

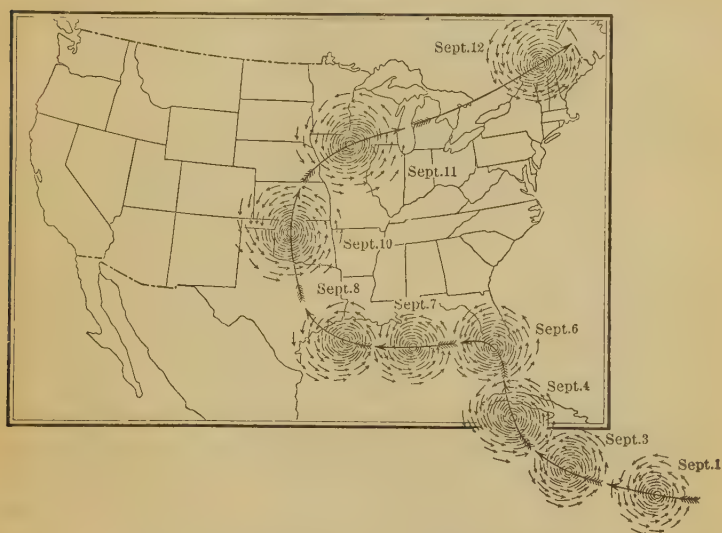


FIG. 35. The path of the Galveston hurricane

Diagrammatic representation of the position of the storm on several successive days. Its intensity was much decreased after it left the Gulf of Mexico. After the United States Weather Bureau

dark and rain may fall. The fall of rain is accompanied by lightning and thunder, as well as by considerable wind. After the storm has passed, the temperature is cooler because the warm air has flowed upward and has been replaced by cooler air from above.

Thunderstorms usually occur in the southerly part of a cyclone during warm weather and in the warmer part of the day, but they may occur even in winter. They move eastward

across the country at a rate of from twenty to fifty miles per hour. They may affect a region many miles wide or be restricted to a fraction of a mile in width. They also vary in severity, but are not commonly destructive.

51. Tornadoes. In the United States, particularly in the cen-



FIG. 36. A tornado cloud

The spirally whirling wind and cloud lift all sorts of objects into the air and sometimes carry them over great distances. Photograph by the United States Weather Bureau

tral part, there are occasional storms (tornadoes) of very great severity but affecting a limited area. Like the thunderstorms, they are due to the excessive heating of the lower air, which is also nearly saturated with water vapor. They differ from thunderstorms in that the ascending current is very strong and has a rotary motion. The movement of the air in such a storm resembles that of water in a whirlpool (fig. 36).

The direction of rotation is always counterclockwise.

A tornado commonly occurs within

the southeast quarter of a cyclone and moves toward the northeast, the direction of the prevailing wind. It moves across the country at about the same rate as a thunderstorm. The condensation of water and the presence of dust and dirt which have been blown up by the whirl make the storm visible as a conical or funnel-shaped cloud, which is whirling rapidly.

The path of a tornado is never wide. It may not be more than 100 or 200 feet in width. Within this path the destruction is often so complete that all buildings, fences, trees, etc. are leveled to the earth or carried great distances.

The velocity of the wind within the central whirl is very great. It has not been possible to measure it. From the character of the results which are produced, it is estimated that the wind



FIG. 37. Buildings wrecked by a tornado

In the foremost building one wall of brick three stories high was torn away, the rest of the building remaining. This was done by the outward pressure of the air within when the tornado pulled the air away on the outside. Photograph by the United States Weather Bureau

velocity within the tornado may be as high as five hundred miles per hour. The tornado at Mount Morris, Illinois, in 1898, and the one which passed from the vicinity of St. Louis, Missouri, across Illinois and Indiana in 1917, of which pictures are shown, carried off heavy objects, such as stoves and pianos, destroyed buildings to the foundation (fig. 37), drove light sticks and straws through or into boards and posts, plucked the feathers from living chickens, and did many other peculiar things.

Fortunately such storms cover such a small area and occur so very rarely that the chance that any one place will be visited by one of them is not great. Tornadoes which occur at sea are known as waterspouts.

52. General circulation of air on the earth. The surface of the earth may be divided into zones, or belts, characterized by different kinds of winds. The belt which we have been discussing is called the belt of westerly winds, because the lower winds are from a westerly direction more frequently than from any other. It is true also that the upper air currents in this region are from the west, as is shown by the movement of the higher clouds. This is always from the west. The winds of this belt are so much disturbed by the passage of the cyclones that it is difficult to see any regular eastward movement until one recalls that the cyclones themselves move eastward. This eastward movement of the cyclones is doubtless due to the fact that they are merely great whirls in the greater mass of eastward-moving air. It will also be recalled that thunderstorms and tornadoes move eastward, as, indeed, is true of practically all weather conditions. It is in the western sky that we usually see the first indication of the coming storm; the first lightning flashes are usually seen in the west; and it is in the west that the clearing of the sky begins after the storm.

This belt of westerly winds, with its cyclones and other phenomena, extends entirely around the earth in this latitude. Mountain ranges which cross the path of the westerly winds have much heavier rainfall on the western than on the eastern side. This is because the winds, as they ascend the western side, are cooled and some of the moisture condenses into clouds and rain, while on the eastern side the air is warming as it descends and becomes relatively dry. A good example of this will be found by comparing the rainfall on the western slope of the Cascade Mountains in Washington and Oregon with the rainfall on the eastern side of the same mountains (fig. 38).

In the tropical regions we have the belt of trade winds on each side of the equator. The great heat of the equatorial re-

gions causes the air to expand and thus become less dense. It is pushed upward in the region of greatest heat,—the heat equator,—which is near the true equator. In this region of rising air there is little wind at the surface of the earth, and it is known as the belt of calms. To the north and south of the belt of calms the air is rushing either southward or northward toward the heat equator. By the rotation of the earth these winds are turned from the direct course they would otherwise pursue, so that in the northern hemisphere they become north-east winds and in the southern hemisphere they blow from the southeast. These winds blow very steadily and are known as trade winds.

53. Rainfall in the United States. Rainfall is very unequally distributed in the United States (fig. 38). It ranges in amount from 100 inches per year in northwestern Washington to 2 inches per year in southeastern California. There are no very large regions in the United States which should be called deserts. However, more than a third of the country is so dry that it cannot be farmed successfully without irrigation or other special means of securing adequate water. The eastern slope, the lake region, and the Mississippi Valley as far west as the middle of the Dakotas and Nebraska are well watered. The plains and mountains of the West have very scanty rainfall excepting on the westward slopes of mountains near the Pacific Ocean.

The rainfall on the Pacific coast is due mainly to the effect of the mountains upon the prevailing westerly winds. The scantiness of rainfall in the mountains and on the plains directly east of them is due to the same thing. The larger rainfall of the Mississippi Valley occurs principally in connection with the cyclones. The air which is swept northward from the Gulf of Mexico into the cyclones carries part of the moisture which produces rain. Farther east the Atlantic Ocean contributes moisture in the same way.

54. Source of moisture for rainfall. Moisture is evaporated from the surfaces of oceans and other large bodies of water. If this moisture chances to be carried by air currents which

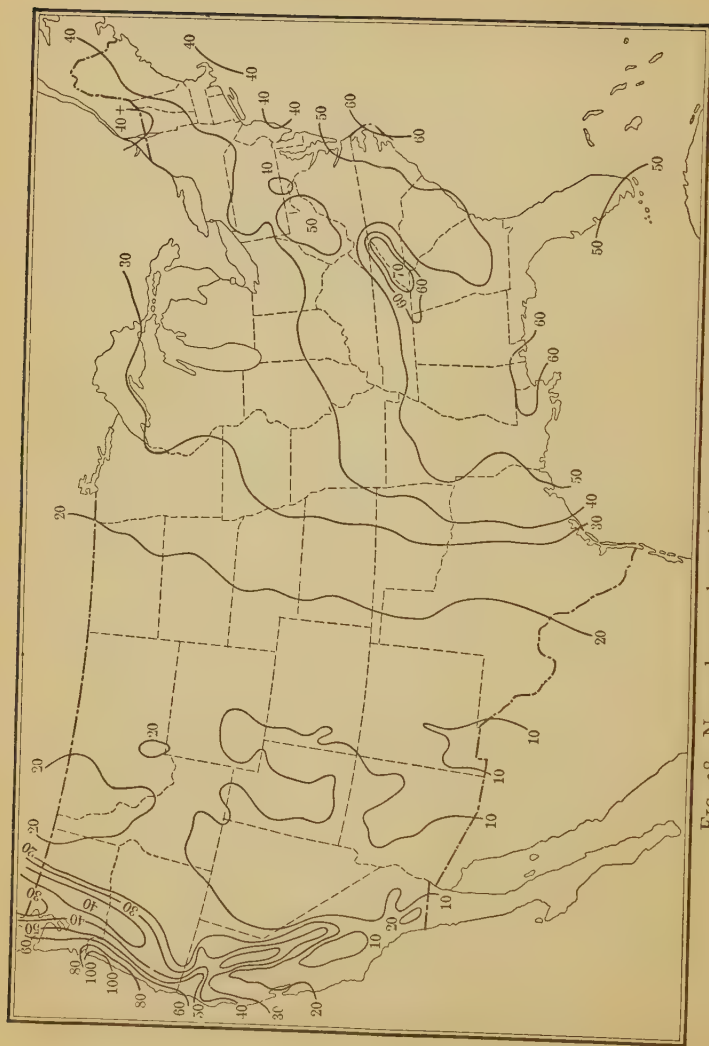


FIG. 38. Normal annual precipitation in the United States

The lines pass through points which have equal precipitation. The figures are for depth of water in inches

later pass over land areas, it may be condensed and fall as rain. Part of the rain finds its way into streams and eventually into oceans or lakes, from which it may again be evaporated, and so repeat its round. It was formerly supposed that this

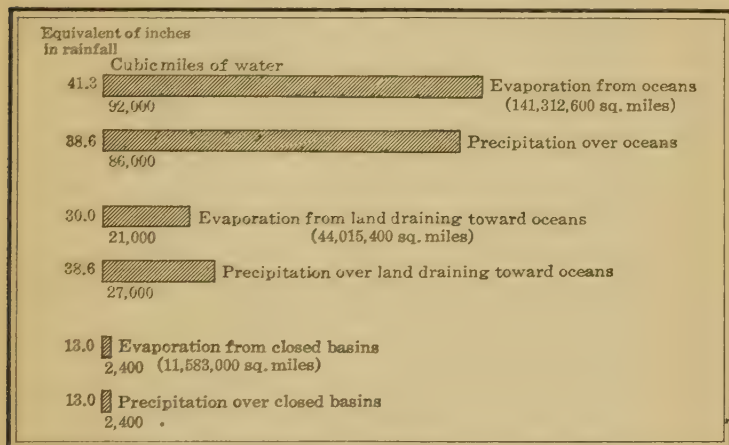


FIG. 39. Circulation of water on the earth's surface

Data and diagrams prepared by Raphael Zon

simple statement is essentially true for all the moisture which appears as rain or snow, but it is now known that the situation is much more complicated.

A study of the diagrams in figure 39 will show that by far the largest amount of moisture which falls comes from the oceans and lakes only indirectly. It has been evaporated from the surface of the land and from vegetation and then falls again as more or less local rains. The significance of this discovery is most important.

It is well known that tall vegetation, like forest trees, causes moisture to flow away or to evaporate from the earth's surface more slowly than is true with quite low vegetation, like grasslands. Areas which are entirely free from vegetation have their moisture flow away or evaporate much more rapidly than

vegetated areas. In areas totally without vegetation any rain which may fall finds no plants or humus to hold it, and hence it usually flows away rapidly. Any of it which does not flow away is soon evaporated and is again precipitated, and this process is repeated rapidly until the land is again left dry and arid. Such regions must then wait until long-distance currents of air bring a new supply of moisture before much if any precipitation may again occur. In forested regions of wide extent evaporation is constantly occurring, thus tending to distribute the resulting rainfall over longer periods. Large areas without tall vegetation seem likely to have their rainfall limited to much briefer periods. Also they have more severe erosion from a given amount of rainfall, since the water flows away more quickly. Most important of all, such areas are less favorable to agriculture and gardening, as well as other types of human industries, since the moisture is not favorably distributed throughout the growing season. It must be apparent that it is important that forests be maintained if a more general distribution of rainfall is to be secured. However, forests are but one of many factors involved, and there are many unsolved problems relating to rainfall.

55. The United States Weather Bureau. The importance of the weather to the people of the country is so great that the government has established a bureau for the purpose of studying the weather and forecasting it as far as possible. While it is not possible always to foretell the weather with certainty, the predictions that are made are fairly accurate and have been of great value to the country.

All forecasting of weather is based upon the weather map. The predictions are based almost wholly on knowledge of the character and actions of cyclones. The usual path of cyclones and the rate of motion have been carefully studied. It is possible to estimate quite closely what a cyclone will do within the next twenty-four hours, and therefore how weather conditions will change. For instance, if it were found that within twenty-four hours a cyclone that is now in the West could be

expected to approach to within a short distance of a certain place, it would be safe to predict clouds and rain for that place. On the other hand, the approach of a high-pressure area would justify the prediction of clear weather.

Most of the difficulties in forecasting arise from the irregularities in the behavior of cyclones. Cyclones sometimes travel in unexpected directions or at unusual rates. Sometimes they disappear entirely, and sometimes new ones make their appearance without any warning. In spite of all these difficulties, forecasting the weather has been brought to a most helpful degree of reliability.

Flood warnings are an important part of the work of the bureau. The storm warnings at ports on the ocean and Great Lakes are the means of saving annually many lives and hundreds of thousands of dollars' worth of property. The warnings of frosts have saved in a single year as much as three million dollars' worth of perishable property in the form of fruits and vegetables. Many well-trained scientific workers are endeavoring to solve weather problems. Each one solved brings forecasting one step nearer to certainty.

CHAPTER V

ATMOSPHERE AND HYGIENE

56. Questions for discussion 1. Why do people fan themselves on hot days? 2. Often in summer one feels quite cool when riding rapidly in an open automobile, and after stopping soon feels very warm. Why? 3. How does an electric fan cause the room to seem cooler? 4. Some people have the practice of keeping the windows in a house closed during hot days. Does this keep the house cooler? Explain. 5. Is an electric fan as effective in keeping one cool on a hot dry day as on a hot moist day? Why?

6. In hospitals patients often speak of being cool after an alcohol massage. Explain this feeling. 7. Do you perspire more freely on a hot moist day or on an equally hot dry day? Why? 8. Why does the air feel more invigorating on a clear day than on a damp, cloudy day? 9. Why does hot weather in Kansas produce less discomfort than weather of the same temperature ordinarily would in New Jersey?

10. A student of hygiene asserts that the air of an ordinary school-room is like the air of a desert. What causes this condition, and how can it be prevented? 11. What healthful purposes are served by the sense of smell? 12. Does the temperature of the human body vary widely from winter to summer?

57. Humidity and comfort. Most of us live in climates in which there is a good deal of difference between summer and winter comfort. We recall the summer days of high temperature and the discomfort we suffered upon some of them. People commonly think that it is on account of the heat, but a record of the actual temperature through a series of hot days is instructive. The hottest days are not always the most uncomfortable. It often happens that a temperature of 95° F. or more does not seem particularly trying, while on another day when the thermometer reads in the 80's everyone is hot and perspiring. Likewise it may happen that two days have exactly the same

temperature but differ widely in the discomfort they cause. If on such days one were to make observations upon the humidity as well as the temperature, he would find that the uncomfortable days are always characterized by high relative humidity. He would notice that ice-water pitchers and cold-water pipes "sweat" profusely, indicating the large amount of water vapor in the air.

On these particularly oppressive days one's skin is always damp and feels sticky, and clothing adheres to the body. Even a slight exertion starts perspiration, and prostrations from heat are not uncommon. Such days are commonly said to be "close," "muggy," or "sticky." Similar conditions may be experienced in an unventilated room, especially if there happens to be a crowd of people in it. Such facts as these suggest that the oppressive days are associated with poor evaporation of moisture into the atmosphere.

58. Evaporation and cooling. When a bather stands on the beach in a wet bathing-suit, no matter how hot the day, he has the sensation of being cool (fig. 40). This sensation continues as the bathing-suit becomes dry. What occurs is that the dry hot air takes up moisture from the bathing-suit. The heat necessary to cause the moisture to be carried away in the air



FIG. 40. The welcome cooling effects of a wet bathing-suit

When the photograph was taken the boy had just come from a dip in the lake

is provided by the human body. This loss of heat, with the accompanying reduction in temperature, causes the feeling of being cold. When all the moisture has evaporated from the bathing-suit, the air seems warm.

If while the bathing-suit is wet the person lies on the beach and covers himself with sand, the sensation of coolness disappears. The sand which is at or near the temperature of the air prevents rapid evaporation and the bathing-suit does not soon become dry when thus covered by sand.

A little ether or alcohol placed on the back of the hand soon evaporates. As it evaporates, it is noticed that the hand feels cool, even cold if this process is long continued. Indeed, we can soon freeze a small patch of the surface if ether is kept rapidly evaporating. Such a process is sometimes used in surgical operations.

The ether or alcohol, like water in the bathing-suit, is heated by the skin; and, being heated, it becomes vapor and passes off into the atmosphere. This obviously uses some of the heat from the body. Since ether and alcohol are substances which are easily vaporized, they change rapidly and thus use heat rapidly. Water vaporizes more slowly and thus uses heat more slowly. Water does, however, vaporize in the same way; and perspiration, like evaporation of ether and alcohol, serves to use heat and to reduce surface temperature. Perspiration is one of nature's devices for reducing bodily temperature. The air will always seem relatively cool when perspiration is evaporating readily; it will seem relatively warm and may be oppressive when evaporation is not occurring.

59. Proving reduction in temperature. It is obvious that the temperatures as shown by an ordinary thermometer do not really indicate the condition of the air as it affects the human body. A device known as the wet-bulb thermometer is better adapted to this purpose. It is so arranged (fig. 41) that the bulb is kept constantly wet with water. Evaporation of this water cools the bulb of the thermometer in somewhat the same way as evaporation of perspiration cools the human body. It

registers a lower temperature than does the ordinary thermometer. The temperature of the wet-bulb thermometer, therefore, is an indication of the cooling effect which adequate evaporation may have upon our bodies. In many of the larger cities it is now common for the city water supply companies to turn on the water in temporary shower devices (fig. 42) for the benefit of the thousands of people who have difficulty in keeping cool.

60. Other uses of perspiration.

Perspiration also serves other purposes, such as removing wastes from the body. Since it does remove these wastes and deposits them upon the surface of the body, care must be taken to wash them away, lest perspiration itself be hindered or even stopped. The odor of the wastes carried to the surface in perspiration serves to warn us of their presence and to announce the fact that a bath should have been taken. Refined people are universally anxious to bathe frequently enough to assist perspiration and to avoid the unpleasant odors which come from it.

61. Hastening perspiration. It may be noted that when ether or alcohol is fanned, evaporation is more rapid, and also the cooling effect upon the skin is greater. This means that more rapid change of the atmos-

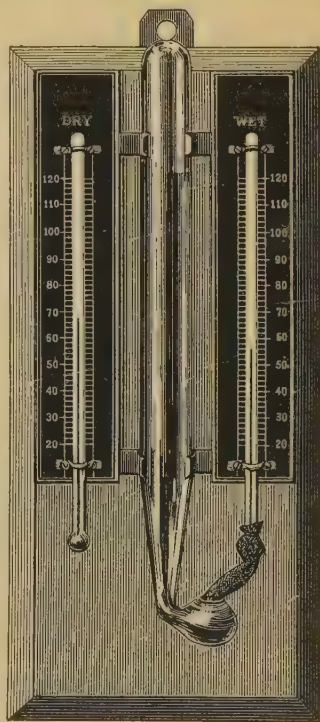


FIG. 41. Wet-bulb and dry-bulb thermometers

The bulb of one of the thermometers is covered with a cloth, which is kept moist by the water in the glass reservoir with which it is connected. Evaporation cools the wet-bulb thermometer, which registers the lower temperature

phere which is in contact with the surface makes possible a more rapid removal of vapor and thus a greater cooling effect. In the same way evaporation of perspiration is hastened by more rapid change of the adjacent air. Fanning and electric fans secure this result. When one drives rapidly in an automobile his body is moved through the air instead of the air being moved, but the same effect is secured.



FIG. 42. The street shower on an August day in a crowded residence district in a city

X62. Retarding evaporation. Sometimes there is danger of too rapid cooling of the body, producing a chill with serious consequences. When one has been running, or walking very vigorously, and has become extremely warm, the tendency is to stand in a strong breeze so as to reduce the temperature as rapidly as possible. Well-trained athletes know that such a practice is dangerous, and usually throw a blanket over themselves instead, even though it temporarily adds to their discomfort. This makes certain that evaporation and cooling will take place slowly enough to avoid danger to the athlete's health.

Similar care should be taken by all persons if they are really to improve their health through exercise and not to injure it.

63. Humidity and ventilation. It is a common experience that when a number of people are in a closed room the air soon seems "close" and oppressive. There are many factors which account for this condition, and some of them are related to temperature and humidity. The human body is at a temperature higher than that usually recorded by the surrounding air. The people in the room therefore raise the temperature of the air. At the same time the large amount of water given off in the breath and evaporated from perspiration increases the relative humidity. When this humidity has become so high that perspiration is evaporated only slowly, it is difficult for the human bodies to remain at normal temperature. The result is that the room seems hot, "close," and oppressive, though the thermometer may not indicate a high temperature.

Temporary relief may be secured by the use of fans, which keep the air in motion and thus increase evaporation of perspiration. The best possible way to correct this condition is to admit a constant supply of fresh air from outdoors. This may always be done by means of windows and doors, or other special openings for ventilation. Change of air in a living-room is usually brought about by adjusting the openings of the room so that the colder air from the outside will flow in and push up the warmer air within. It is easy to construct a piece of apparatus (fig. 43) by means of which to study the movements of air.

The odors given off by the human body either through perspiration or in the breath also add to the discomfort in poorly ventilated rooms. It is true, also, that the body uses oxygen from the air and gives off some carbon dioxide. The decrease of oxygen or the increase of carbon dioxide may sometimes be serious, but usually before this occurs the other factors mentioned will compel ventilation.

Whatever may be the reason that the air of a room becomes unsatisfactory, the remedy is always the same—the admission of fresh air from outdoors.

64. Dry air in houses. While, as set forth in the preceding discussion, there is often discomfort caused by excessive humidity or by impure air, the rooms of homes and schools are often too dry. A relative humidity of something like 35 per cent may seem quite low. It is, however, higher than usually is found in dwelling-houses and schoolrooms in winter time. If as high humidity as 35 per cent could be maintained regularly in schoolrooms in winter, that would be quite acceptable.

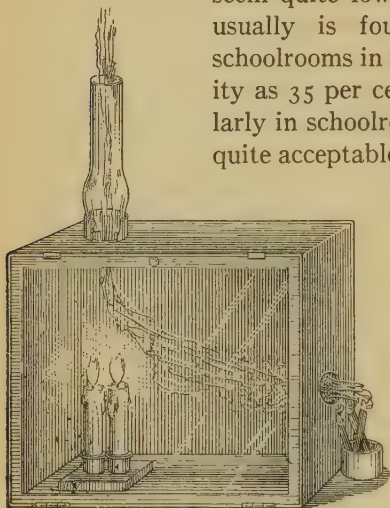


FIG. 43. The "smoke box" experiment

The back, top, and bottom are of metal; the ends and front are of glass, the front being a hinged door which fits tightly. The right end has a small opening near the bottom, and the top has a small opening near the left end. Smoking sticks are placed near the end opening, and lighted candles are placed within the box below the top opening. What can be learned from the experiment?

Air which is continually hot and dry does not provide a healthful environment. Persons who live in such air are often uncomfortable and restless, and the sensitive linings of the nose, ears, and throat become dry and parched, thus making them more susceptible to cold infections. Such persons often are troubled by sleeping poorly. Furthermore, they are affected by air more readily and more seriously than are others, since in the cold dry air the skin evaporates water more rapidly and produces the chilly feeling. Such persons often urge higher temperatures in the room, when lower tem-

peratures and higher relative humidity are what are really needed. Tightlly closed, highly heated, relatively nonhumid houses are disease breeders, while moderate temperatures, open windows, and abundant moisture and fresh air are favorable to good health. It is hard to set too high an estimate upon

the hygienic importance of securing proper conditions of moisture and temperature in the air about us.

65. Adding moisture to the air. In addition to admitting a constant supply of fresh air with whatever moisture the outside air may contain, various devices have been suggested to remedy the condition of low relative humidity. Some people place a large open dish of water in the living-rooms. Small tanks of water are sometimes placed upon the backs of radiators, and most hot-air furnaces have tanks containing about two gallons of water so placed that the water will evaporate and pass into the rooms. Experiments to determine whether these devices are effective have failed to show much gain in humidity from their use. The gain from the furnace tank was shown to be about 1 per cent. Even with specially designed furnaces which evaporate from 12 to 15 quarts per day the results were not so good as desired. In one experiment it was possible by special effort, in very cold weather, to evaporate from 20 to 24 quarts per day. In this last case the relative humidity was raised to 35 per cent at a temperature of 20° C. (68° F.). No device has yet been invented which is entirely satisfactory in keeping dwelling-houses and schoolhouses as humid as they should be. Steam jets in the heating-room from which air passes into schoolrooms have proved fairly satisfactory, and the so-called washed and humidified air now coming into use gives promise of great improvement.

CHAPTER VI

DUST, MOLDS, AND BACTERIA OF THE AIR

66. Questions for discussion. 1. Is there commonly more dust in the air over cities or over the open country? 2. What causes milk to sour? meat to decay? fruit juice to ferment? 3. If milk does not sour when allowed to stand for several days in a warm place, does this indicate that it is of good quality? What might prevent it from souring? 4. If a bacterium should divide and thus produce two bacteria once in each thirty minutes, and continue to do so for twenty-four hours, how many would there be at the end of that time as the result of the successive divisions?

5. Why are objects less likely to mold in a house which is carefully and frequently cleaned than in one which is not well cared for? 6. What is the source of the mold which sometimes appears upon bread if the bread is left for some days in a tightly closed box? 7. What are the bluish-green patches that appear on gloves or shoes which have been left in a warm, damp closet?

8. Would surface wells in cities and other densely inhabited places commonly be safe sources of supply for drinking-water? Why? 9. Are the water supplies at summer resorts and picnic grounds in your vicinity safe sources for drinking-water? 10. Should we prosper better if there were no bacteria or other organisms which produce decay? 11. Why should schoolroom floors be cleaned and oiled frequently?

67. Dust everywhere. Dust consists of very small, solid particles which are carried by the air. Larger particles settle very rapidly, but very small ones fall through the air so slowly that they remain floating for a long time. Astronomers are of the opinion that particles of dust have passed around the earth without alighting. If a wind is blowing, dust may be carried great distances in very short periods of time. The abundance of dust in the air becomes obvious when we see a beam of sunlight crossing a darkened room. All the bright points dancing in the light

are bits of dust. At such a time we really see only the larger dust particles, since most of them are too small to be seen in this way. The fact that a covering of dust has accumulated on furniture which was carefully cleaned but a few hours before is one of common observation. When we go out of doors, dust often gets into our mouths and nostrils, irritates our eyes, and clings to our clothing. Indoors we cannot escape it, for even though we close the house it finds a way through the smallest cracks. It is upon the food we eat, particularly if we purchase articles from street stands or in stores where the food is displayed uncovered. In cities the air is often so filled with solid particles, whether called dust or smoke, that it is impossible to see very far. Dust is not wholly absent even in the clear air over the desert or the ocean.

If a piece of smooth glass is washed, then placed while wet in the cleanest air available, it is likely that some dust will soon be found to have settled upon it.

68. Sources of dust. What is this dust which we might eat with fruit purchased from a street stand at some dusty corner? In modern life very many processes are constantly producing dust which rises into the air. The automobile, the shop, the feet of millions of tramping people, are constantly grinding materials into dust. Undoubtedly a large part of the dust comes from the débris of the street, ground up by the hoofs of horses and the wheels of vehicles. A glance into the street will enable us to see some of the things which are being crushed to powder and which will later make part of the common dust as it is picked up by the wind and whirled about. Some particles are bits of unburned carbon (smoke or soot), and in cities this may make up a large part of the dust. Bits of wool and cotton from the clothing of all sorts of people, fragments of hairs from the coats of animals, dead cells from the skins of people and animals—all these things and many more enter into the composition of dust. Some of the dust particles may irritate the delicate surfaces of the nose and lungs. A larger particle in the eye may occasion serious trouble. If these and the household in-

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conveniences were all, we might be inclined to think dust merely an annoyance. It is more than that, however, as we shall see.

69. Living dust—mold and yeast. We cannot get away from the dust, but must learn to live with it in the best way possible.



FIG. 44. Fermentation by yeasts

Yeast plants were placed in the sugar solution within the jar. Bubbles of gas formed by fermentation rise through the solution, and large numbers of yeast plants settle as sediment at the bottom

Information about some of the particles in the air may be secured if we will perform certain experiments. Cut a slice from a fresh loaf of bread, using a clean knife. If this bread is exposed to the air for a while and then covered in such a way that it cannot get dry, within a few days it will be covered with a growth of fine white threadlike material called mold. Mold is a living plant, but in appearance it is quite unlike the plants with which we are most familiar.

In a few days there appear on the mold small black heads in which a fine, dustlike black powder is produced. These dustlike particles are called spores. Spores are easily blown about by the wind, and if one of them alights upon a piece of bread or in any other favorable place, it is able to grow into a new mold plant.

If a weak solution of sugar in water is exposed to the dust of the air and allowed to stand for several days, it ferments. Bubbles of gas rise through the liquid. This gas is carbon dioxide. After a while the sugar can no longer be found in the solution, but in its place there is a small amount of alcohol, and a peculiar odor is present. A scum collects at the surface of the liquid and usually at the bottom also (fig. 44). The microscope shows that this scum is made up of very small living yeast plants.

If a sugar solution is boiled in order to kill any yeast that may be in it, and is then inclosed so that no yeast can enter, fermentation will not occur. If the solution is again exposed to the air after boiling, fermentation will follow. This shows that the yeast gets into the solution from the air and that it is one cause of fermentation.

70. Living dust—bacteria. If a thin layer of beef broth or similar substance which is stiffened with gelatin or agar is poured into shallow dishes, another interesting experiment may be performed. The material must first be heated to destroy any living things that may have been in it. One of the dishes should be uncovered to the dust of the air and allowed to remain so for perhaps fifteen minutes, and then covered again; the other dish should not be uncovered at any time. After several days it will be

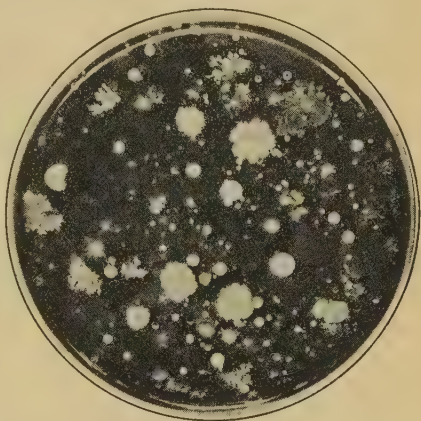


FIG. 45. Colonies of bacteria

Each of the circular or irregular patches represents one colony of bacteria. The bacteria grew in a thin layer of nutrient agar. The dish is 9 cm. in diameter and contains 350 colonies of bacteria. The colonies have arisen from the multiplication of bacteria which fell upon the agar during fifteen minutes' exposure out of doors

found that the gelatin in the dish which was exposed to the air has upon it a number of small round spots (fig. 45) which are usually white but are sometimes pink, orange, or yellow. These spots will enlarge from day to day. Each of the spots consists of millions of very minute bacteria which can scarcely be seen even with a microscope. These are living plant cells of the simplest structure. Each of the bacterial groups or colonies has resulted from the growth and increase of one or a few bacteria which fell upon the gelatin when it was exposed to the air.

We learn from these experiments (1) that a part of the dust of the air consists of things that are able to grow and multiply if they happen to alight upon favorable substances; (2) that there are at least three kinds of living things represented in the air—bacteria, yeasts, and mold spores; (3) that each of these is able to grow vigorously if only it falls on the right kind of

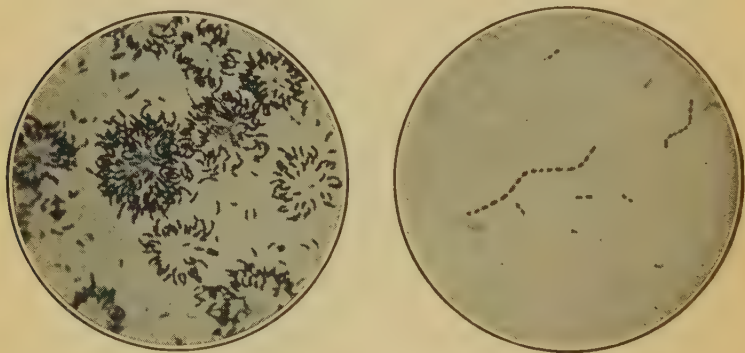


FIG. 46. Photomicrographs of bacteria

These photographs were taken through a high-power microscope. The small, dark bodies are the bacteria, very highly magnified

substance; and (4) that all of them are so numerous that they are likely to fall upon every favorable place and, of course, upon unfavorable places as well.

71. Size and growth of bacteria. Bacteria are the smallest of living things, often measuring not over $\frac{1}{1000000}$ inch in diameter. Some kinds are considerably larger than this, while others are much smaller (fig. 46). Only the very highest powers of the microscope will give information about their internal structure. There is good reason to believe that there are bacteria so very small that they are quite invisible even with the best microscope.

New bacteria are produced by division of the old ones. After one has grown to adult size it may divide into two, each of which may continue to grow and divide. The division may be

repeated as often as once in every twenty minutes, though usually not so frequently. Bacteria feed upon and destroy plant and animal materials, and on account of the rapidity with which they multiply they are usually found in very large numbers.

72. Study of yeasts, molds, and bacteria. The study of these forms of life is of great importance, and the methods that must be used in studying them are different from those used in studying larger plants. One who wishes to know much about them must give his attention to this branch of science alone. On account of the danger to man from disease-producing bacteria, the science of bacteriology has been taught largely in connection with the study of medicine, but its importance in other respects is coming to be more commonly recognized. Yeasts and molds have little relation to disease, but are of great importance in daily life and in industry because of the changes which they produce in foods and other materials.

73. Relation of bacteria to decay. It is chiefly bacteria, yeasts, and molds which cause the change known as decay in plant and animal substances. One way to prevent decay, therefore, is to prevent the growth of these organisms. The most successful method of preventing harm by bacteria, yeasts, or molds is to kill those present by the use of heat or chemicals, and then to prevent the entrance of others.

Chemicals are sometimes used to preserve milk, formaldehyde being added in small quantities for this purpose. Formaldehyde is effective in preserving the milk, but it is very objectionable in a food material. An interesting and proper use of formaldehyde is in preserving specimens in museums, not in preserving food for human beings. Other chemicals are used in canned goods for the same purpose, but in general it may be said that any chemical which will destroy bacteria is not likely to be a suitable article of food. Most states have laws which prohibit the use of injurious preservatives in food. What are the laws in your state? The preservation of food by means of salt, sugar, or vinegar is a common, effective, and desirable

method. This is practiced in the canning of fruits and other food products. Yeasts and molds are almost constantly present on the skins of all fruits and sooner or later cause the fruit to spoil unless they are destroyed. In canning, the fruit is first boiled to kill yeast and mold. It is then sealed air-tight while hot, in order to exclude all living things. If both operations have been successful (that is, if there are no living things in the can and no opportunity exists for them to get in), the fruit will keep indefinitely. Yeast and bacteria cannot grow if enough sugar is added to the fruit. It is a matter of common experience that jellies and jams may be kept for a long time without being tightly sealed. This is not a satisfactory protection against molds, however, unless the food is kept in a cool dry place.

The process by means of which all life of every kind is destroyed by heat, chemicals, or other means is known as sterilization. The decay of substances may also be hindered through drying or refrigeration. Many foods, such as apples, grapes, plums, peas, and beans, may be kept for a long time if they are dried and kept in a dry place. Preservation by drying is rapidly increasing in its use. In case of many fruits and vegetables the skin serves as sufficient protection for a long time if they are kept dry and cool and where there is a good circulation of air. These measures protect against the growth of molds.

74. Cause of disease. Bacteria that are able to grow in the bodies of men, animals, and plants frequently produce more or less serious diseases. In many cases the bacteria are easily transferred from one person to another, and such diseases are said to be infectious. Other disease bacteria are distributed through the agency of air or water.

Examples of bacterial diseases are boils and carbuncles, blood poisoning, lockjaw, pneumonia, diphtheria, typhoid fever, influenza, tuberculosis, leprosy, cholera, and the plague. Recently we have come to realize that common colds are due to bacteria and are infectious. We should be careful, therefore, not to spread colds by coughing and sneezing.

If all pupils who have colds will remain away from school until they are well, they not only preserve their own health but avoid spreading disease to others. Experiments have shown that such a plan produces a large reduction in the total school days lost from illness in one school system. In places where people must live in crowded conditions (fig. 47) it is especially necessary that care be taken to guard against spread of disease.

75. Useful bacteria. Bacteria are of direct use in many manufacturing processes. In vinegar-making the fermentation that

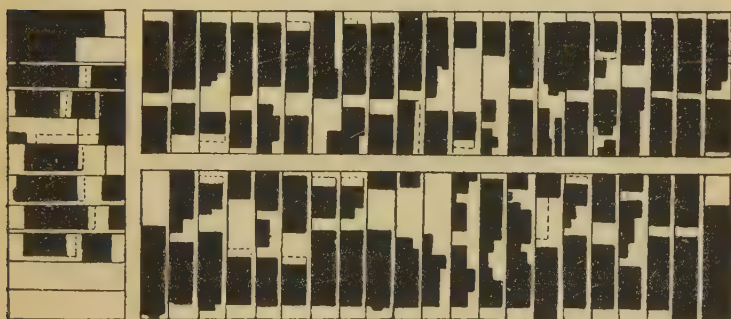


FIG. 47. Diagram of a crowded city block

The dark areas represent buildings. These buildings house sixteen hundred or more persons, and in such crowded quarters it is difficult to prevent the spread of disease. After Report of the Department of Health of Chicago

produces the sour substance in vinegar is the result of bacterial action. Other organisms cause the change in cream known as "ripening," and the flavor of butter is due, in part at least, to bacteria. In cheese-making the work of bacteria is indispensable. The difference in flavor of the different varieties of cheese is due largely to the different kinds of bacteria which have assisted in the ripening, though some kinds of cheese are ripened by certain molds.

76. Bacteria in cultivation. On account of the value of certain kinds of bacteria they are sometimes cultivated, in order to have them always on hand. For instance, it has been found

that if cream is sterilized and then inoculated with certain kinds of bacteria, the cheese made from this cream will always have the desired flavor. If this is not done, the flavor will depend upon the bacteria that may chance to get into it from the air, and the results may not be at all desirable. It is quite probable that in the future we shall domesticate many kinds of bacteria for which we find use.

Other kinds of bacteria are useful in agriculture. They grow on roots of clover, alfalfa, etc. and enable these plants to thrive better than they would without the bacteria. These special kinds of bacteria are sometimes cultivated and supplied to farmers whose land does not contain the desired kinds of bacteria.

77. Yeast in bread-making. One of the most useful plants is the yeast which performs an essential part in bread-making. The yeast feeds on the sugar in the dough, and in so doing produces alcohol and carbon dioxide. The carbon dioxide is prevented from escaping by the elastic dough, but expands the dough and makes the bread light. The alcohol evaporates during the process of baking.

CHAPTER VII

HYGIENIC CONTROL OF DISEASE GERMS

78. Questions for discussion. 1. What disease has caused the most deaths in your community during the past year? How was the disease transmitted from one person to another? 2. What precautions are taken in your community to secure pure water and milk? 3. What is your community doing to decrease the number of flies? 4. Is your home well defended against flies? 5. Is the breeding of mosquitoes about your home prevented?

6. If impure surface water runs into a well from the top, is it necessary to draw all the water from the well to purify it or only the first few feet at the top? 7. Why is expectoration on sidewalks and in street cars forbidden? What is your state law on this question? 8. Why are there laws prohibiting public drinking-cups? 9. Baker's bread is handled by more people before being used than homemade bread. How does this affect the probability that harmful bacteria will be present on this bread?

10. Which is to be preferred, clean, certified milk or ordinary milk which has been pasteurized? 11. Why is machine-made ice often used in regions where there is much cold weather as well as in regions that are warm? 12. What are your state laws relative to quarantine in case of infectious diseases? 13. Why should all urge that quarantine laws be enforced?

79. Good health a protection against bacteria. In discussing bacteria it must constantly be kept in mind that people who are well nourished, who sleep well and enough, and who keep their bodies well exercised and clean are not likely to have diseases. Even if such persons come in contact with disease-producing bacteria, their sound and vigorous bodies readily prevent the germs from growing or doing injury. It is thought that many, possibly most persons, have been exposed to many diseases without having the diseases develop, merely because their bodies were in such good condition that they could easily protect themselves.

Therefore, as we discuss the means of distribution and of prevention of diseases, let it be clear that it is most important of all that human bodies shall be maintained in good health, which is the best insurance against attacks by disease germs.

80. Means of distribution. No harm can actually result unless disease germs are carried from those who are sick to those who are well. We have seen that the air is one means of distribution, but many others exist. Substances upon which bacteria are growing sometimes become dry and powdered, such as the street dust of which we have spoken. The bacteria are then blown about in air currents and, with the remainder of the dust, settle wherever they may. The air is never free from them, although they are more plentiful at some times and in some places than in others. Water is also a prominent agency in the distribution of bacteria and will be discussed in connection with our consideration of water supply.

Certain kinds of disease-producing bacteria are most commonly communicated more or less directly from person to person. Insects are agents of great importance, and investigations of the past two decades have given most interesting evidence regarding the ways in which some of the most destructive diseases are dependent upon insects for distribution. The mosquito, flea, and cattle tick are especially bad offenders in this respect.

81. Bacteria upon carelessly handled bread. A careful study of loaves of bread has been made to ascertain how many bacteria there are upon the surfaces of the loaves. Bread was secured from various parts of a large city and from people who handled and sold it in many ways. It was found that unwrapped bread had more bacteria upon it than wrapped bread. The following table of results is most suggestive:

	Average number of bacteria on each loaf
31 loaves from dirty shops	64,970
39 per cent of all loaves of unwrapped bread . .	14,000
22 per cent of all loaves of unwrapped bread . .	2,500
45 per cent of all loaves of wrapped bread . . .	848
55 per cent of all loaves of wrapped bread . . .	371

Obviously, if the fresh bread is wrapped in clean paper, it will be a much less important carrier of bacteria. Few of the bacteria upon the samples of bread were found to be disease-producing, but unclean bread is not especially attractive, even if its load of bacteria does contain but few that produce disease. It is a notable fact that since the first publication of such studies as that just described, the practice of wrapping bread has become much more common. A careful study of other common food substances which are handled by many persons, or not carefully handled, might produce equally striking evidence regarding the distribution of bacteria.

82. Protecting ourselves and others. The diseases most commonly transmitted from person to person are those which enter

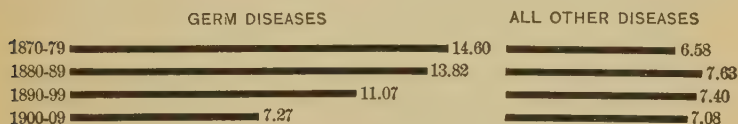


FIG. 48. What it means to know about disease germs

In the first years mentioned the idea of germs as cause of disease was just becoming recognized. The diagrams show the number of deaths, per hundred thousand population, from germ diseases and from all other diseases in one of the largest American cities. Note the decline in preventable diseases

the lungs or alimentary canal through the mouth or nose, such as grippe, diphtheria, colds, tuberculosis, and typhoid (fig. 48). Since persons who are well are contaminated through these sources, it is obvious that persons who have the disease must be the source of the trouble. Diligence is essential for the protection of yourself and others. It is best always to use a handkerchief when coughing or sneezing. Spitting on sidewalks, streets, and in other public places is even worse than spitting in private houses, since less attention is given to cleaning in public places. The quick drying of the sputum in the open air rapidly makes it a part of the dust. In the past two decades the growing knowledge of the spread of disease germs has made the spitting-habit so indecent that it is rapidly disappearing.

Hands rapidly accumulate bacteria-laden dust from stair rails, door knobs, pencils, books, and other objects of common use. Protect your mouth against the entrance of everything except clean food and water. Many states have laws regarding the use of public towels and drinking-cups and the display of uncovered food. Is this true in your state?

83. Transmission of typhoid bacteria. Within the body of a person who has typhoid fever the number of bacteria may become enormous and may produce such injury as to cause death. No matter how many typhoid bacteria there may be that affect this person, no other person would catch typhoid from him unless some of the bacteria were transmitted to the second person. The way to prevent transmission is to make sure that all bacteria from a person who has typhoid are promptly killed. This is most difficult, for it is not easy to sterilize everything that might carry bacteria. Furthermore, some people who have recovered from typhoid continue to have living typhoid bacteria in their bodies for several years, thus making possible continuous distribution of disease germs. Such persons are known as typhoid carriers and are a public menace.

84. Importance of pure milk and water. Milk and water have often been the means of carrying typhoid bacteria. Many cases show conclusively that when a dairyman or some member of his family has typhoid, many of the people whose milk supply comes partly or wholly from his dairy may take the disease. Lack of care has made possible the introduction of typhoid germs into the milk, and it is distributed to patrons who unsuspectingly purchase the material which may give them the disease. If the water and milk are not polluted with typhoid bacteria, or if, when polluted, they are sterilized, they do not carry the disease. Milk may be pasteurized (that is, heated for twenty minutes to between 140° and 150° F.), and this kills the typhoid germs.

The number of all kinds of bacteria in a cubic centimeter of milk or water is often very large. There may be wide variations in the number, due to the different ways in which milk

and water are handled or to the length of time they have been allowed to stand in places favorable to the growth of the bacteria. Thus, in the city of St. Paul, Minnesota, an investigation showed that in samples of milk secured from delivery wagons there were 409,477 bacteria per cubic centimeter, while "dipped store milk" (milk which had been standing in bulk) contained 8,206,000 bacteria per cubic centimeter. In Newark, New Jersey, it was found that "bottled wagon milk" contained 416,000 bacteria per cubic centimeter, while "dipped wagon milk" contained 3,623,333 bacteria per cubic centimeter; that milk delivered to a store contained at the time of its delivery 280,000 bacteria per cubic centimeter, while eight hours after its delivery the number had increased to 1,488,000 bacteria per cubic centimeter. In many cities the law now requires that milk be bottled before distribution.

85. Results of improved hygienic conditions. In the city of Chicago, prior to 1908, less than 2 per cent of the milk was pasteurized, and the average yearly death rate from typhoid per 100,000 population was 24.8. In the years 1909-1911 between 50 and 75 per cent of the milk was pasteurized, and the average death rate from typhoid fever per 100,000 population was 12.4; in 1916 the death rate had decreased to 5.1 per 100,000. There are many other unquestioned instances of lowering the human death rate through improvement of hygienic conditions, as shown in the tables on the following pages.

In cities there are many cases of typhoid which are contracted by residents while traveling or visiting away from home. The health officers of cities have learned to expect an increase in the number of cases of typhoid at the season of the year when large numbers of people are returning from their summer vacations. Conditions in the city are not to blame for these cases, and if they are subtracted from the total number occurring, the showing for milk and water supplies is much improved. In the case of Toronto the number of deaths due to typhoid contracted in the city was only .6 per 100,000 population in 1923, while the total number of deaths from typhoid was 2.6 per 100,000.

REDUCTION OF TYPHOID FEVER IN BOSTON

In the city of Boston a better system of milk and water supply was introduced during the closing decade of the last century and the first decade of this century. In 1910 it was claimed that about half of the milk used in Boston was pasteurized. In the light of these facts the following table, showing Boston's annual death rate from typhoid during this period, is instructive.

Year	Typhoid Deaths per 100,000 Population ¹
1891-1895	31.1
1896-1900	30.6
1901-1905	22.4
1906-1910	16.0
1911	9.0

REDUCTION OF TYPHOID IN THREE CITIES

Year	DEATHS PER 100,000 POPULATION		
	Chicago	Pittsburgh	Toronto
1903	31.8		17.4
1904	19.6	142.1	24.7
1905	16.9	98.8	17.2
1906	18.5	130.3	27.6
1907	18.2	125.2	21.3
1908	15.8	48.7	20.9
1909	12.6	24.6	24.7
1910	13.7	27.9	44.2
1911	10.7	25.8	21.6
1912	7.6	12.7	13.2
1913	10.6	19.3	11.4
1914	6.9	15.2	8.1
1915	5.3	10.3	1.9
1916	5.1	8.8	6.9
1917	1.6	11.6	3.8
1918	1.4	10.9	3.1
1919	1.2	6.1	2.6
1920	1.1	5.2	2.3
1921	1.1	4.1	3.1
1922	1.1	4.9	1.5
1923	1.9		2.6

¹ E. O. Jordan, General Bacteriology. W. B. Saunders Company.

TYPHOID DEATH RATES IN 1922 IN AMERICAN CITIES HAVING OVER 500,000 POPULATION

A study of the death rates in leading American cities for recent years shows a remarkable reduction in this disease. The highest recorded death rate from typhoid was that of Chicago for the year 1891, when 1997 persons, or 173.8 per 100,000 population, died from typhoid. Better milk and water supplies, together with other improvements, have contributed to the favorable results shown below.

NAME OF CITY	Population, 1922, estimated by U. S. Census, March, 1923	Total Deaths reported from Typhoid
New York	5,839,746	129
Chicago	2,833,288	31
Philadelphia	1,894,500	53
Detroit	1,019,333	50
Cleveland	854,565	19
St. Louis	795,008	35
Boston	764,017	11
Baltimore	762,222	30
Los Angeles	634,866	24
Pittsburgh	607,902	30
San Francisco	529,792	12
Buffalo	528,163	19

86. The use of anti-typhoid vaccination. Although it is highly important to prevent distribution of disease germs, attention should also be directed to important advances in knowledge of methods of treating people so that the disease may not develop even if they are exposed to it.

During the Boer War in South Africa imperfect attempts were made to control typhoid by a treatment similar to that which has saved multitudes of children from diphtheria. Gradually the method has been improved, so that in 1909 it was recommended in the United States army as a voluntary protection, and the results were so favorable that in 1911 it was made compulsory. To prove the early claim regarding typhoid vaccination, look at the following tables of cases and deaths in the army and navy up to the year 1915.

TYPHOID FEVER IN THE UNITED STATES ARMY

Year	Cases	Deaths
1906	210	12
1907	124	7
1908	136	11
1909	173	16

TYPHOID FEVER IN THE UNITED STATES NAVY

1909	189	17
1910	193	10
1911	222	15

AFTER ANTI-TYPHOID VACCINATION WAS MADE COMPULSORY
IN THE ARMY AND NAVY

1912	57	2
1913	22	4
1914	13	0
1915	15	1

87. Anti-typhoid vaccination becoming compulsory. In the World War anti-typhoid vaccination was enforced in the American armies. Public misunderstanding and other difficulties made it impossible to have all vaccinations made as promptly and effectively as desired. The following figures from the surgeon-general's office are based upon the number of admissions to hospitals because of typhoid and paratyphoid. The ratios are per thousand per year.

YEARS	TYPHOID FEVER				PARATYPHOID FEVER			
	Admissions		Deaths		Admissions		Deaths	
	Number	Ratio	Number	Ratio	Number	Ratio	Number	Ratio
1916	96	.54	5	.03	410	2.32	4	.02
1917	297	.44	23	.03	20	.03		
1918	768	.30	133	.05	107	.04	6	.00238
1919	467	.47	71	.07	86	.09	5	.00497
1920	14	.07	1	.00477				
1921	8	.04	1	.004849	3	.01		
1922	1	.01			1	.01		

A study of the above table shows that the number of cases of illness from typhoid and the deaths from this disease may be almost wholly eliminated under conditions of vaccination such as the army makes possible. The values of typhoid vaccination are now so widely accepted that persons who are planning to take any extended journey are first vaccinated against this disease. The results are remarkably successful, and it seems probable that typhoid vaccination of all citizens might be equally successful.

88. Typhoid bacteria carried by flies. Disease bacteria may be transmitted by many agencies. For example, typhoid bacteria may live in waste animal matter and may then be carried by flies and deposited upon solid food or in milk or water, and later gain entrance to the human body. The flies are not causes of disease; they are merely the agents of transmission. If



FIG. 49. The house fly

The rough and hairy body of the fly is well adapted to the carrying of bacteria.

After Howard

no typhoid bacteria had been allowed to get to the organic matter upon which the flies fed, they could not have carried them. Since many people are so careless as to allow distribution of disease bacteria to places from which flies may carry them, it is important that we should destroy the flies, with the hope of preventing further distribution of bacteria (fig. 49).

89. The life history of the house fly. An individual house fly lays about 120 eggs. They are laid in manure or other refuse. The eggs hatch in from six to eight hours, forming larvæ. The larvæ (fig. 50) are small white wormlike creatures called maggots. For about five days they feed upon the material in which

the eggs were laid, after which each one changes into a quiet stage known as the pupa. After five or six days the pupa changes into the adult fly. In a few days the new flies may lay eggs, and another generation is begun. In ten days 120 flies may develop from one pair of house flies. Suppose that half the flies of the second generation are females and that they lay eggs within two days. At that rate how many flies might be produced from a single pair during four summer months?



FIG. 50. Stages in the life of the house fly

A, egg; B, larva; C, pupa; D, mature fly

90. How house flies carry bacteria. The mouth and feet of the house fly are covered with small roughish hairs. When magnified under a lens these hairs show clearly that many bacteria may lodge there as the fly walks upon the refuse which usually forms its food. The bacteria may then be deposited from the fly's feet upon any food or any person upon which the fly may alight. Some of the bacteria are swallowed by the fly and may later be excreted and deposited at its next lighting place—perhaps upon someone's food. The transmission of bacteria by the feet of flies is shown in the illustration on page 87.

91. Disposal of house flies. If the refuse in which flies lay their eggs and in which the larvæ live is removed, no new crops of flies can be produced. Traps may be so arranged as to catch

adult flies, after which they may easily be killed. Obviously coöperation is needed to eliminate this insect, for so long as any person in a community supplies the materials for the growth of flies, just so long will that community have flies. It is also to be noted that people who will leave refuse exposed so that flies breed in it are likely to be the kind of people who would allow disease bacteria to get into the refuse, thus making possible their further distribution by flies. If no disease germs were allowed to get into the refuse, the increased number of flies would be annoying but not necessarily of any importance relative to disease.

92. Cleanliness and disease. Individual and civic cleanliness are important. Our standards of taste and of decency should demand that sewage, garbage, and all kinds of refuse be

removed at proper times and in proper ways. More important is the care which will insure that disease germs may not be allowed to pass to other people. When, in 1898, the United States took possession of Havana, Cuba, the harbor, naturally one of the finest in the world, was filled with refuse from Havana. In the city open sewers carried bacteria-laden sewage. Flies, mosquitoes, dogs, and rats had ready access to this filth. During the year 1898 one human being in each twelve died—the terrible price that ignorance and carelessness exact. A far more difficult conquest remained. It is easy to locate and fight a political

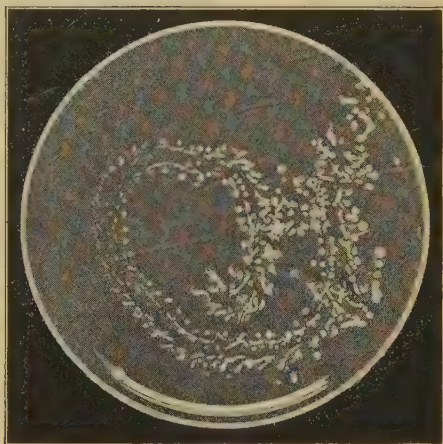


FIG. 51. Bacteria carried by a fly

A plate of agar culture medium over which a fly was allowed to walk. Colonies of bacteria have developed where the fly touched the culture medium

enemy, but it is very hard to fight ignorance, especially when it is backed by unfounded prejudice. Consequently the Cuban of Havana, who had been set free from Spain, had to be set free from himself. Martial law prevailed until the harbor was cleaned, a new and pure water supply was found, a more sanitary system of sewage disposal was installed, and last, but not least, those who were in charge of sick people were compelled to sterilize all material containing disease bacteria, so that the agents of transmission could not carry disease germs. Soon average health returned to Havana—a conquest of more import than her release from Spain. Similar triumphs of science have now been made in many parts of the modern world. Many more are still needed.

93. Malaria caused by an animal organism. The mosquito, like the fly, is a carrier of disease germs, but in this case only certain kinds of germs are transmitted, while almost any kind may be carried by the fly. In the case of malaria the germ is carried by mosquitoes. Therefore we must discuss both the disease and the mosquito. When a person has malaria his red blood corpuscles are infected with an extremely small one-celled animal. One of these malarial organisms lives within a red corpuscle for a brief period (three days in the case of one kind of malaria), and by the end of that time has undergone repeated divisions, resulting in the formation of several of the one-celled animals. The wall of the corpuscle breaks, and all the newly formed malarial parasites are set free in the liquid of the blood. It is usually just after many such parasites are set free in the blood that the malarial chill ensues. The germs may enter other red corpuscles, and in due time another crop of their kind will have been produced and another chill ensue.

94. The life history of the mosquito. Mosquito eggs are laid in little groups on the surface of the water (fig. 52, A). When the eggs hatch, the individual emerging from each egg is a little squirming creature, called a larva, but popularly known as a "wiggler" (fig. 52, C). The eggs may hatch in less than a day after they are laid. The larvæ grow for about seven days in

warm weather, but longer if the temperature is cool or if food is scarce. Finally, each larva changes into the pupa (fig. 52, *F*), which lives in the water three days or more. The pupa changes into an adult mosquito. The adult lives in the air, but lays eggs on the surface of the water. When the eggs are produced, another life cycle is begun.

In its larval stage the mosquito feeds upon very small living things in the water. It frequently comes up and protrudes through the surface of the water small tubes by means of which a fresh supply of air is gained. The adult female mosquito may secure her food by biting through the skin and sucking the blood from man or other higher animals.

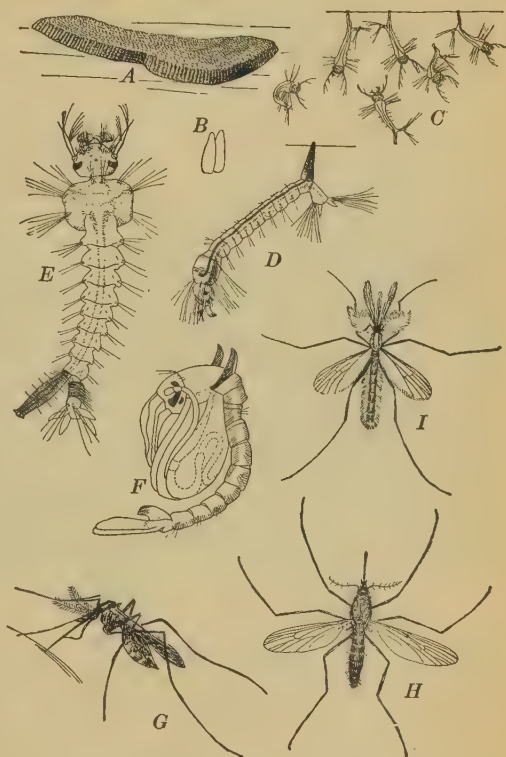


FIG. 52. The common mosquito (*Culex*)

A, egg raft; *B*, eggs; *C*, young "wigglers," or larvæ; *D* and *E*, views of larvæ; *F*, pupa; *G* and *H*, females; *I*, male. *A*, *B*, *C*, *G*, *H*, and *I*, somewhat enlarged; *D*, *E*, and *F* very much enlarged. After Howard

95. How the mosquito carries malaria. When a mosquito of a certain kind (*Anopheles*, fig. 53) feeds upon human blood, it injects a small amount of salivary fluid into the wound that it

has made. If the person has malaria, the mosquito secures blood which may carry malarial germs. These germs multiply rapidly within the mosquito, really living in a way quite different from their life in the human blood. Some of the germs get into the mosquito's salivary glands. When the infected mosquito bites a second human being, germs are injected into the wound with the salivary fluid. These may produce the disease in the person thus infected.



FIG. 53. Two kinds of mosquitoes

Above is the malarial mosquito (*Anopheles*); below is the yellow-fever mosquito (*Aedes aegypti*). Males at the right and females at the left

96. How to destroy mosquitoes. It is evident that if we can remove the mosquitoes we shall be free from danger of infection with malaria. Since these insects pass the early part of their lives in ponds, lakes, and quiet water, they cannot reproduce if the water is drained away. Where such drainage is possible, it is a good method of guarding against the diseases carried by mosquitoes (fig. 54). Another method of destroying these insects is to pour kerosene over the water. The oil spreads over the surface of the water and kills the eggs.

The larvæ and pupæ cannot secure air through the surface film of oil, so they die. The adults cannot get through the oil film to the surface of the water to lay more eggs, and if they get into the kerosene in their attempt to lay eggs, they are killed.

Still another method of getting rid of them is to subject them to their natural enemies. Fish eat the larvæ, and therefore the mosquitoes will be less abundant if the ponds are stocked with fish.

A very small body of water, such as that in an old tin can or in a partially filled track of farm animals, may be ample for the development of a crop of mosquitoes. It is necessary to give attention to such places in order to prevent their growth.

97. Different kinds of mosquitoes. There are several different kinds of mosquitoes. Only one of these, the genus *Anopheles*, carries the malarial germ. Our most common mosquito (*Culex*)

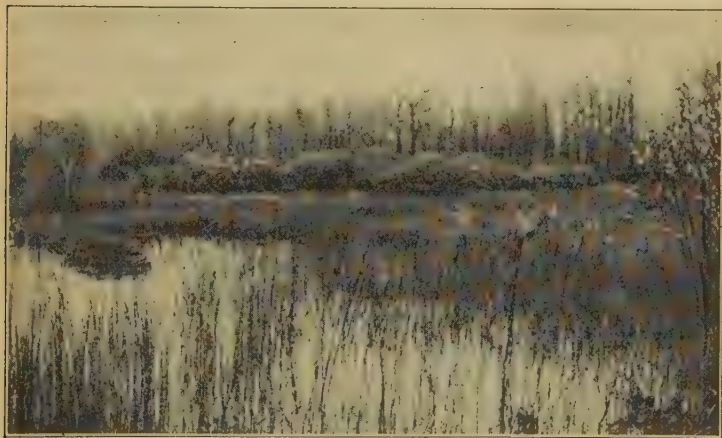


FIG. 54. An ideal mosquito breeding place

In shallow ponds, in swampy places, in rain barrels and old tin cans, and in other places where water can stand mosquitoes may develop very rapidly. In such places as that shown here a good supply of fish will serve to keep the mosquitoes limited to small numbers

does not, so far as we know, carry any disease germ. Yellow fever is produced by another animal germ, carried by the mosquito known as the yellow-fever mosquito (fig. 53).

98. Disease germs distributed by other insects. House flies and mosquitoes are not the only insects that transmit diseases. It is known that the germs of bubonic plague are transmitted from person to person by a kind of flea that commonly lives upon rats. Rats are subject to the plague, and when they die from it the infected fleas leave their bodies and find new hosts.

If they alight upon the body of a human being, their bites will probably infect the person with the plague bacteria. Very obviously the disease is much less likely to attack the careful and cleanly person, living in a well-kept dwelling, than it is to attack his less cleanly, vermin-infested neighbor. The only complete protection from this disease and others possibly carried by rats is to be secured by the total destruction of the rat population. The facts mentioned above explain how it is that in such a country as India the natives may die of the plague in great numbers, while their European neighbors, with cleaner surroundings, usually escape. During the Middle Ages, when all dwellings, from the hovel of the peasant to the palace of the king, were unsanitary and infested with vermin, epidemics of the plague and other diseases frequently swept Europe, but in modern times nothing of the sort is likely to occur in enlightened nations.

The very deadly spotted fever is carried by a tick, and another tick carries the Texas fever of cattle. Various other insects, such as bedbugs, roaches, and certain flies, have been accused of carrying different diseases. As science discovers more and more about the relations of insects, bacteria, and disease, it becomes more and more indecent for people to allow such insects to live in their homes.

CHAPTER VIII

STRUCTURE OF THE AIR

99. Questions for discussion. 1. How is it that if a small amount of musk or other strong perfume is released in a closed room, the perfume may soon be detected in any part of the room, possibly in adjacent rooms? 2. What becomes of milk or sugar when it is thoroughly stirred in coffee or tea? 3. Could you take the milk or sugar out of the coffee or tea after it was thoroughly stirred into it?

4. Do you know of any substances which can be changed from solid to liquid and from liquid to gas, or changed in the opposite direction? 5. Is the substance destroyed during any of these changes? 6. What happens to a solid, such as ice, when it is changed into a liquid? when it is changed into a gas? 7. When a tumbler full of water has a drop of red ink placed in it, how can the ink become distributed throughout the water?

8. If a room is full of air, how is it possible for another gas which is released in the room also to fill the room? 9. What is the nature of the structure of gases which makes it possible for one gas to pass throughout a room which is already occupied by another gas?

100. Filling with air. In Chapter II we found that the volume of a body of air may be changed very greatly. For instance, if only enough air is pumped into a football bladder or toy balloon to round it out, one can take it between his hands and compress it to less than half its original volume. Similarly, an automobile tire may contain enough air so that it supports the machine, and yet, although we say that it is "filled" with air, we know very well that if we apply the pump we can force more air into it. As we continue to pump, the tire gets firmer and it is harder to operate the pump, showing that there is greater pressure in the tire. There seems scarcely any limit to the amount of air that can be forced in, so long as our strength endures and the tire does not burst.

Many familiar substances would not behave as air does. If a container were filled with water or with sand, we know that we should not be able to put more of the same material into the container without removing some of that first put in.

We may reverse the above experiment, and pump air out of a container instead of into it. Suppose we attach an air pump to a bottle, and pump one half of the air out of the bottle. Is one half of the bottle filled with air and the other half empty, as would be the case if water had been used? The air remaining has expanded so as to occupy the whole interior of the bottle, though it is of course correspondingly "thinner." Indeed, if means can be found to remove all the air but a millionth part, the small amount remaining will spread out evenly through the whole space.

Air and other gases seem to possess the power of indefinite expansion. A gas always expands so as to occupy the whole space that is available to it.

101. Gases occupying the same space. Another interesting property of air and other gases is their ability to pass through one another. If there is a leaking gas pipe in a closed room, the odor of gas can soon be noticed in any part of the room. The fact that the odor can be found in all parts of the room indicates that the gas has spread to the most remote corners. How did it get there? If there were currents of air, it might be carried by the currents, but the same result is observed even if the air is quiet. It seems, therefore, that the small amount of gas that has been released from the pipe in one part of the room has somehow managed to distribute itself more or less evenly through the whole room without being much affected by the fact that air is also present. In other words, although the room was occupied by the gas which we know as the air, the gas which escaped from the pipe has spread itself through the room as if it were the only gas present. |

If other gases are used, the same results follow; careful tests show that when several gases are in a space at the same time, each one of them soon becomes evenly distributed throughout

the space. This property that gases have of mingling with one another when in contact, even if not stirred, is called diffusion.

102. Problems about gases. The very interesting facts mentioned above have been a subject of interest for hundreds of years. Many people have asked, How can one substance pass through another substance, as when illuminating gas diffuses through the air from one part of the room to another part? Certainly two persons or two books cannot occupy the same space at the same time. Furthermore, how may a substance be made to occupy less space, as it does when air is compressed? Or how can anything expand indefinitely, as air does?

If we try to discover an answer to some of these questions by comparing with the behavior of some familiar substance, as wood, iron, or stone, we find that none of these substances will expand or contract in any large amount. It is only when we have broken one of them into extremely small pieces, as when wood is reduced to the finest sawdust or rock to the finest powder, that it can be distributed over an indefinite space. Also the pulverized substances can be intermingled with each other, as sand with sawdust, in a manner similar to the intermingling of two gases by diffusion. Thus it is only when solid substances are reduced to separate small particles that we can imitate the things that actually occur with gases. This has suggested that possibly the behavior of gases can be explained if we suppose that they are composed of many very minute and separate particles.

Such a suggested explanation, sometimes little better than a guess, is one of the first steps in thinking out the solution of a problem. The suggestion must not be accepted until it has been examined to see where it leads and whether it explains the facts that raised the problem. Scientists are always very careful not to accept a suggested explanation or theory as correct until it has been proved by careful comparison with a great many observed facts.

Let us follow the suggestion about the structure of the air and see whether it agrees with and explains the known facts.

103. A theory about the air. In the attempt to answer the questions that we have been asking about the air and also to explain many other matters, scientists have formed a theory to account for the facts. This theory is that the air is not a perfectly continuous substance, but that it is formed of a great many particles, each a little distance from the other. These particles, called molecules, are believed to be extremely small. It is believed that they are in rapid motion, and that one molecule moves in a straight line until it strikes another, when it rebounds and again moves in a straight line. It is supposed that molecules are continually moving and striking one another at very short intervals. This theory of the structure of the air and of other substances is called the molecular theory. As the question is more thoroughly investigated further evidence is found that agrees with the theory. As yet nothing has been found that is opposed to this explanation. All scientific men have come to accept it as a reasonable explanation and one that is probably true.

104. Molecular theory applied to compression and expansion. Will this theory assist us to understand the questions raised in the preceding discussion? Since, according to the molecular theory, the air is composed of molecules at some distance from one another, somewhat like gnats in a swarm, we can understand that when air is compressed, these molecules merely move closer together so that there are more of them within a given space. When air expands they move farther apart. A small amount of air will quickly expand to fill a large space, since the molecules of which it is composed are moving rapidly in all directions and thus distribute themselves throughout the space.

105. Gas pressures. How can a group of moving molecules exert the pressure that we know air exerts? If you strike a blow upon a punching-bag, it is pushed to one side and immediately returns; but if you hit it again as it starts to return, and continue to strike one blow after another very rapidly, the bag will remain pushed to one side as long as you continue to strike. The molecules are believed to be doing something very

similar to this. They not only strike against each other but, if the gas is inclosed, they also strike against the walls of the containing vessel. Since they are so small, each blow is very insignificant indeed; but there are so many of them that they strike innumerable blows every second upon each square inch of the containing surface, and the sum of these blows is very great. The result of all these blows is that the gas exerts pressure against the walls which confine it; for instance, against the inside of the rubber tire.

106. Heat, molecular movement, and gas mixtures. As the temperature of a gas increases, the speed with which its molecules move increases. Since they move faster, they strike harder when they hit the walls of the tire or other container, and the pressure is greater. This agrees with our observation, for we find that pressure exerted by a confined gas always increases with the temperature.

According to this theory, when two or more gases are mixed, their molecules are intermingled, but each kind of molecule remains unchanged. When some means of sorting the two kinds of molecules is available, the two gases may be recovered unchanged. A gas like the air may be made up of a mixture of molecules of several different kinds of gases, just as a swarm of gnats or flies may be made up of several kinds of gnats or flies.

107. Usefulness of the molecular theory. The molecular theory thus enables us to understand the compression and expansion of gases, gas pressures, the effect of heat on gases, and diffusion and mixture. Scientists who are interested in studying such matters find that it enables them to explain very many more other phenomena, and that by its use they have been able to make many new discoveries of great importance. All students of the structure and behavior of matter now accept the molecular theory.

It has been determined that in air or any other gas at the usual atmospheric pressures there are about 44,250,000,000,000,000,000 molecules to the cubic inch. This number is entirely too large for anyone to comprehend it easily. For our purposes

it is enough to think of it as very greatly exceeding the number of the human population of the earth.

108. Liquids and solids. It may be more difficult to believe that liquids and solids are likewise composed of molecules, but this is thought to be the case. It is not very difficult if we recall the fact that gases can be condensed into liquids; for instance, when steam becomes liquid water, or in the formation of liquid air. Likewise, liquids may be frozen into solid form. It follows, then, that solids and liquids, like gases, are made of molecules.

There are some differences, however. The molecules of a liquid seem to move about readily—almost as readily as they do in a gas, but they do not have the same tendency to fly apart. Thus the liquid changes form, but it remains the same in volume. It does not readily expand and is not easily compressed. The solid also is not easily compressible, since its molecules do not readily shift their positions. It has a permanent shape. The spaces between the molecules in a liquid or a solid are much smaller than in a gas, but there must be some space, else we could not dissolve substances in water. Even so compact a substance as gold will absorb certain other substances, and it is believed that the molecules of the dissolved substance find their way into the spaces between the molecules of gold.

If alcohol, which is lighter than water, is carefully poured into a test tube half filled with water, at first the greater part of the alcohol will float upon the water, but after some time it will be found that the two liquids have become evenly mixed. If the experiment is carefully performed, it will be discovered that the volume of the alcohol and water mixture is less than the volume of the two before they are mixed. This is taken to indicate that the molecules of one have been able to occupy space between the molecules of the other, thus reducing the volume and showing that spaces exist between the molecules. A lump of salt or sugar dropped into a vessel of water will dissolve and diffuse throughout the water. Diffusion occurs in liquids as it does in gases.

CHAPTER IX

CHEMICAL COMPOSITION OF THE AIR

109. Questions for discussion. 1. Will a lamp burn if the top of the chimney is closed? 2. Why are there holes in the base of the burner of a lamp or lantern? 3. How does the kerosene or candle oil reach the flame? 4. Is there a nonluminous portion in the flame of a kerosene lamp? in a gas flame? 5. What should be done to correct a smoking lamp chimney? 6. Why does a person hold his hand around a match when he first lights it? 7. Is similar protection needed when starting a wood or coal fire? in starting a gas fire?

8. Are the flames of a candle, lamp, or fire from coal or wood always driven upward? Why? 9. Why is it dangerous to pour gasoline in a room where there is a flame? 10. How do you explain the presence of water on the inside of a lamp chimney immediately after lighting the lamp? 11. Why does this water later disappear? 12. Would kerosene or gas flames used for lighting affect the need for ventilation in a room?

13. Why does carbon dioxide sometimes remain in wells or cisterns when most gases would escape? 14. Why do workmen lower a lighted lantern into an old well before they descend into it? 15. Why is carbon dioxide valuable for use in fire extinguishers? 16. It is said that the first thing to do in case a person's clothes catch fire is to cover the person with a blanket or robe. Why? 17. Why do iron fences rust? 18. How may we prevent objects from rusting?

110. Air and fire. It is said that some time ago an employee in a hotel found it necessary to enter a room that had not been occupied for a number of days. Upon opening the door he was surprised to discover that there had been a fire in the room while it was unoccupied and tightly closed. The fire had started in some unknown way, burned part of the furnishings, and had become extinguished without being noticed by any human being. There are, of course, many ways in which a fire may be

started, but once started why did it go out while there was plenty of fuel left? It is difficult to be sure of the answer in the case of the hotel room, since no one was there to learn all the facts, but a simple experiment suggests a possible explanation.

If a candle is lighted in the open air, it burns brightly; but if it is put in a box so tight that no air can enter, the flame will soon die out. The fire in the tightly closed room may have been extinguished in the same manner. It is commonly known that a supply of air is necessary for a fire. Sometimes we say that the air is used up, or burned up, in the fire. But is this true? If we examine the box in which a candle has been extinguished by "lack of air," we find that the box is not empty. If we plunge it under water, bubbles of gas will escape from it just as they would have done before the candle was put into the box. Plainly, either the candle while burning used up the air and exchanged for it some other gas which was given off from the candle or it burned only a part of the air, leaving the remainder in the box; or possibly both things occurred.

It is not uncommon to see destructive fires which destroy parts or all of buildings or whole groups of buildings. In some cases the fire stops when all the available fuel has been consumed. In others, water may have been used to stop the fire (fig. 55). To understand what really occurs in burning it is necessary to study a very small fire carefully. A candle flame is selected for this purpose.

111. The candle flame. Careful observation readily shows two conspicuous regions of a candle flame. There is a central cone-shaped part which gives off little or no light, and this is surrounded by a bright, light-giving layer (fig. 56). This central part of the flame may be called the dark zone or dark layer, and the other the bright layer. If you look closely you may be able to see on the outside of the bright area a thin blue layer. For the purposes of our study we need not discuss this blue area separately from the bright area, but we should recognize the existence of both.



FIG. 55. Fire, water, smoke, and steam

An aerial photograph of a fire in a New York City business building. Note the streams of water being thrown from the streets and from the tops of neighboring buildings

Attention is immediately drawn to the bright layer, and we may suspect that a good deal of the burning is going on here. If a toothpick or a match stick is held across the lower part of the flame, it quickly begins to burn in the bright zone, but the part which is in the dark zone is not even charred for some little time. It is therefore clear that the greater heat is to be found

in the bright part and in the thin blue outer layer of the flame. This raises the question as to what the central part of the flame is composed of and what is happening in the bright part.



FIG. 56. The candle flame

Note the general form of the flame, the light outer part, and the dark center

112. The dark part of the flame. Since the central or dark part of a flame is transparent, it appears likely that it is composed of some kind of gas. If it is a gas, we should be able to conduct some of it outside of the flame where we can experiment with it, by putting the end of a glass tube in the dark part of the flame. The outer end of the tube should be higher than the inner end, in order that the hot gas may ascend. If this is carefully done, and a lighted match is applied to the upper end of the tube, a small flame of burning gas will result (fig. 57). This indicates that the substance in the center of the flame is in fact a gas, and that it is a combustible gas.

The flame burns at the top of the wick, but does not come down the wick to the solid part of the candle. The heat soon forms a cup in the top of the candle by melting the center of it. This cup is filled with melted tallow or wax. The melted wax is absorbed by the wick and travels upward through it, just as ink is absorbed by blotting-paper and spreads through it. As the melted wax goes up the wick and gets closer to the flame, it gradually becomes hotter and finally begins to burn.

The melted wax or oil gets so hot that it changes from a liquid into a gas, and then burns as it is passing away from the wick. The burning is not taking place at the surface of the wick, but occurs chiefly in the outer part of the flame. In producing the flame it is the gas and not the solid candle which is burning.

113. Products of the flame. We have now traced the wax from the candle up the wick and through the dark part of the flame to the bright, burning region. Let us see whether we can find any trace of the wax in either gaseous, liquid, or solid form outside of the burning region, and thus learn whether it passes through the flame unchanged. There are several ways in which to get information on this question. We might use the glass tube again, placing the inner end just outside of the flame. In doing so we find no trace of the inflammable gas. Or we may hold a cold piece of metal in the flame, such as a large piece of iron. In this case we shall find some black soot on the iron and also the thing we least looked for, —water,—but no candle wax. An empty bottle held upside down over the flame gives the same result. The candle wax which goes into the burning part of the flame does not come out as wax. It undergoes a change on the way through the flame and comes out as quite a different substance.

114. Water in the flame. Water is one of the things which appear in the flame. Where did the water come from? Either it must have come from the air or it must have come from the flame. If you will refer to your study of the conditions which bring about the condensation of water vapor from the

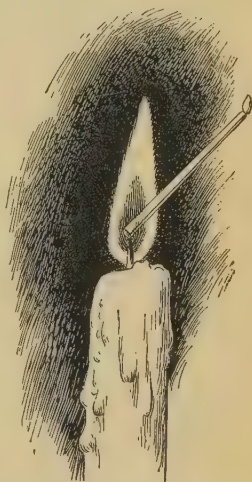


FIG. 57. Inflammable gas secured from the flame

By the use of a tube the unburned gas from the center of the flame may be conducted to the outside and there burned

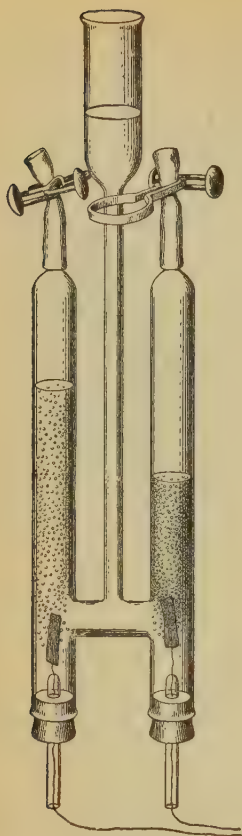


FIG. 58. The decomposition of water

By use of an electric current the water is decomposed into the hydrogen and oxygen of which it is composed. The upper, clear region in the right-hand tube contains hydrogen, and the upper part of the left-hand tube contains oxygen. The volume of hydrogen is twice that of the oxygen

air (Chapter III), you will recall that it condenses from the air only when the temperature is lowered, and not when it is raised. Hold the metal in the flame again, and when water begins to condense remove it and touch the wet spot. It will be found to be warm, much too warm to have condensed water from the air. In fact, when exposed to the air of the room the water quickly evaporates. The water which condenses on the metal does not come from the air. It must come from the flame. Since there is no water supplied to the flame other than the little that is in the air, it is evident that it is made in the flame. Some of the molecules that reach the flame must either be changed or combined to form molecules of water. Since the candle wax goes into the flame and apparently disappears (see section 112), while water makes its appearance in the flame, may it be that the water is in some way made from the candle wax? Before we can answer that question we ought to know of what water and candle wax are composed. The best way to find out what substances compose water is to discover what is produced when water is decomposed.

115. Decomposition of water. An electric current is necessary in the experiment which follows. At a later

time we shall study electric currents, but at present we are interested only in what happens to the water. When the ends of two platinum wires are put into water containing a little acid and a current of electricity is passed through the water between the wires, it is noticed that bubbles of gas arise from both wires. By suitable apparatus it is possible to collect these bubbles until there is enough gas to allow us to examine it (fig. 58). It will be noticed that the volume of gas that may be collected from one wire is about double that collected from the other. Both gases are colorless and look like air. These gases both come from the water, and they will be given off as long as the current flows through the water. One of them, that of the greater volume, will burn readily with a pale-blue flame; the other will not burn, but a splinter burns much more brilliantly in it than in the air. The gas which takes fire readily is called hydrogen; the one which makes the splinter burn more brilliantly is oxygen. They can be caused to unite, and when they unite they form water. We therefore conclude that water is made up of two substances, hydrogen and oxygen, and that the electric current causes them to separate.

It appears strange that water, a liquid, should be composed of two gases, but such is the case. Are the two gases merely mixed? If so, we should expect to find that the results of the mixture would be a gas. If hydrogen and oxygen are mixed, as was done with air and illuminating gas in an earlier experiment, the result is a mixture of gases, nothing more. Water is something different from a mixture. In fact, if hydrogen and oxygen are mixed and a flame is brought to them, the mixture will explode. After the explosion we cannot find either of the gases, but instead there is water or water vapor. Making a mixture is quite a different thing from forming a new substance. If hydrogen and oxygen are mixed, there are in the mixture two kinds of molecules, the molecules of hydrogen and the molecules of oxygen. When water is formed, there are molecules of only one kind, the molecules of water. The hydrogen and oxygen combine to form the water molecules.

116. The molecule of water. The theory held by scientific men is that the molecule of water is not a simple thing, that it is composed of two kinds of particles. These particles are called atoms. The atomic theory states that each molecule is commonly made up of two or more atoms and that these atoms may be of the same kind or of different kinds.

Each molecule of water contains both hydrogen and oxygen atoms. When water was decomposed by the electric current, twice as much hydrogen as oxygen was secured. That would suggest that in the molecule there is twice as much hydrogen as oxygen. Study by chemists has proved that in a molecule of water there are two hydrogen atoms and one oxygen atom.

Chemists use a certain letter as an initial letter or symbol for a certain kind of atom. Thus, H stands for a hydrogen atom and O for an atom of oxygen. If there is more than one atom, a small figure is written below and to the right of the letter to tell how many atoms are meant. Written in this way the symbol for a molecule of water is H_2O .

117. Explanation of some chemical terms. When a substance is made up of molecules each having two or more kinds of atoms in them, as in water, it is clear that it is possible to separate such a substance into two or more different substances, as was done with water. Such a substance is called a compound substance. Water is a compound. A substance whose molecules have in them only one kind of atom, such as oxygen, cannot be separated into simpler substances. It is called a simple substance (element). Hydrogen, oxygen, iron, silver, lead, copper, and gold are examples of simple substances.

When a compound is separated into simpler compounds or into its elements, the process is called chemical decomposition. Have you seen an example of chemical decomposition? It is sometimes said in such a case that the compound has "broken down." Any change in a substance in which the molecule is changed by atoms being taken away from it, added to it, or exchanged for others is called a chemical change. So long as the molecules remain the same, there is no chemical change.

118. Table of elements. The table on page 108 contains the names of the more important simple substances, their symbols, and a few words describing their appearance and condition at ordinary temperatures. Those marked with a star are metals. Look over the table and note what familiar substances are simple substances or elements. There are in all between eighty and ninety known elements. This table of some of the better-known elements is presented not to be memorized, but for interesting reference.

119. Formation of water in the flame. How was the water formed in the flame? After what we have learned we should expect to find that the water had been formed in the flame by some sort of chemical change. Hydrogen and oxygen unite to form water. The flame is a place where chemical changes are occurring.

The wax is a compound containing hydrogen and carbon; the air is a mixture containing oxygen and several other gases. When the wax is melted and then turned into a gas by the heat of the flame, this gas mixes with the air, and the atoms of hydrogen leave the other atoms and unite with the atoms of oxygen which are in the air. The compound thus formed is water. When hydrogen and oxygen unite, the union produces great heat, and at the resulting high temperature the water remains in a state of water vapor. It is only when this water vapor is cooled, as by contact with a cold object, that it changes into the liquid form and becomes visible as drops of water.

The flame of the candle consists principally of gases heated to a high degree by the changes which are taking place in the flame. The gases in the candle flame with which we are already somewhat familiar are the vaporized wax, water vapor, and the gases of the air. A flame is always composed essentially of burning gases, but these gases may not always be those that we have found in the candle flame.

120. Other products from the flame. It was said that the candle wax is a compound containing hydrogen and carbon, and that the hydrogen which unites with the oxygen is taken away

TABLE OF CHEMICAL ELEMENTS

NAME	SYMBOL	DESCRIPTION
*Aluminium	Al	A white or silvery solid, very light in weight.
Antimony	Sb	A bluish-white solid.
Arsenic	As	A gray solid; it and its compounds are poisonous.
*Barium	Ba	A solid.
Bismuth	Bi	A solid.
Boron	B	A solid.
Bromine	Br	A dark-red liquid, much heavier than water.
*Calcium	Ca	A solid.
Carbon	C	Commonly a black solid, but when crystallized it may be transparent; diamonds are crystallized carbon.
Chlorine	Cl	A pale-greenish gas with a suffocating odor.
*Chromium	Cr	A solid.
*Cobalt	Co	A solid.
*Copper	Cu	A red solid.
Fluorine	Fl	A very pale-yellow gas.
*Gold	Au	A heavy yellow solid.
Helium	He	A light, noninflammable gas.
Hydrogen	H	A transparent, colorless, odorless gas.
Iodine	I	A shining, purplish-black solid.
*Iron	Fe	A silver-gray solid, readily tarnished.
*Lead	Pb	A soft, heavy, silvery solid.
*Magnesium	Mg	A silvery solid, very light in weight.
Manganese	Mn	A solid.
*Mercury	Hg	A silvery-white liquid, very heavy.
*Nickel	Ni	A solid; white, hard, not readily tarnished.
Nitrogen	N	A colorless, odorless gas.
Oxygen	O	A colorless, odorless gas.
Phosphorus	P	A waxy solid, spontaneously combustible in air.
*Platinum	Pt	A silvery solid, very heavy.
*Potassium	K	A solid, but easily cut with a knife.
Silicon	Si	A solid.
*Silver	Ag	A white solid.
*Sodium	Na	A solid, but soft enough to be easily cut.
Sulphur	S	A yellow solid, forming many strong-smelling compounds.
*Tin	Sn	A white, moderately hard solid.
*Zinc	Zn	A bluish-white solid.

from the wax. When the hydrogen is taken away from this compound—that is, when the compound is decomposed—the carbon atoms are left. The small particles of carbon float upward in the flame and are heated red-hot or white-hot. These white-hot particles of carbon give out light, and therefore the part of the flame in which the white-hot carbon is present is the part from which the light comes.

The substance which we call carbon is familiar to us as electric-light carbons, charcoal, lampblack, soot, etc. If a cold object is held in the flame of a candle for a moment, soot, which is carbon, is deposited upon it.

Some of the carbon may be seen to pass upward from the tip of the flame as smoke; but if the candle is well trimmed and has the proper supply of oxygen, there should be little or no smoke. Carbon as well as hydrogen is able to unite with oxygen, and though there is much carbon in the flame, very little of it passes away from the flame in the form of soot. It unites with the oxygen of the air to form a compound made up of carbon and oxygen, known as carbon dioxide. Can we recover the carbon dioxide formed in the flame?

121. Carbon dioxide formed by the flame. If a candle or other flame has been allowed to burn for a time in a bottle, and if limewater is then poured into the bottle and shaken slightly, the limewater will become milky. If we do the same with a bottle in which the flame has not burned, the limewater remains clear. This shows that there is something in the bottle that was not there before the flame was put into it. Chemists tell us that the substance which caused the limewater to become milky is a gas composed of carbon and oxygen. Is it an element or a compound? We may burn some charcoal (carbon) in a jar filled with pure oxygen. In that case anything that is formed can contain only carbon and oxygen, since nothing else was in the jar. If we test the results of this burning by the same means as before, the limewater turns white, showing us the evidence of the same substance. This substance which is produced by the burning candle is a compound of

carbon and oxygen and is formed by the union of the oxygen of the air and the white-hot carbon particles in the flame.

The proper abbreviated formula to represent a molecule of carbon dioxide gas is CO_2 . What does this formula mean?

122. Some further facts about carbon dioxide.

Carbon dioxide gas may be made in many ways besides burning. The most convenient, perhaps, is the method of producing it by putting hydrochloric acid on marble (fig. 59), or by use of apparatus similar to that used in the yeast experiment discussed on page 70. However produced, carbon dioxide is always the same. If we collect it in a bottle, it is found

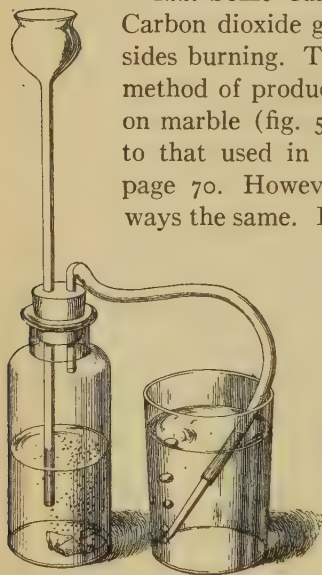


FIG. 59. A carbon-dioxide generator

The action of the acid on marble decomposes it, releasing carbon dioxide, which escapes through the bent tube. Additional acid may be added through the funnel

that the gas is perfectly clear and colorless. It will not burn, but instead it extinguishes fire. It may seem strange that things will not burn in carbon dioxide when the gas is composed partly of oxygen. It must be remembered that the oxygen atoms are joined to the carbon atoms and therefore are not free to unite with anything else. Since the oxygen atoms will not leave the carbon atoms of the carbon dioxide, there is no free oxygen to maintain the burning of a flame, and therefore the flame is extinguished, or "goes out," for lack of free oxygen.

Carbon dioxide is about one and one-half times as heavy as air and therefore can be collected in an open bottle. With care it may be poured from one bottle to another. It is familiar to us as the gas that bubbles up in our soda water and in other effervescent drinks and as the important substance in chemical fire extinguishers. We make use of it in cooking to raise bread,

cake, and biscuit. Sometimes it occurs in wells, cisterns, sewers, and in mines, where it is called choke damp. One may drown in it as truly as in water, since it fills the lungs but does not supply any free oxygen for respiration. There is a very small amount always present in the air. The importance of this will be discussed in the following chapter.

123. Gases of the air. We have already found that the air consists of several gases. These are merely mixed; they do not form a compound. The most striking one of those that we have been studying is oxygen. It makes up about one fifth of the volume of the air. Of carbon dioxide there are only about 3 parts in 10,000 parts of air.

There is another gas present in the air in large quantities. It is called nitrogen. It will be discussed in connection with the food of plants and animals. Several other gases have lately been discovered in the air; namely, argon, helium, krypton, neon, and xenon. Dust particles also are always present, and some of these are of great importance.

Below is a table showing the more important gases which, in addition to water vapor, are commonly found in the air, and the average amount of each, given in percentage. The exact percentage cannot be given because the amounts vary slightly from time to time.

COMPOSITION OF AIR

(Approximately)

Nitrogen		78 per cent
Oxygen		21 per cent
Argon		1 per cent
Carbon dioxide		$\frac{3}{100}$ of 1 per cent

124. Abundance of oxygen. Oxygen is the most abundant simple substance upon the earth. In an uncombined state it makes up about one fifth of the air, as noted above. It is found in combination with almost every known simple substance, forming eight ninths (by weight) of water and about one half of the rocks of the earth's crust. It is estimated that about

50 per cent of the earth is oxygen. Its importance in our lives could scarcely be overestimated.

125. Nitrogen and argon. While oxygen is a very active substance chemically, readily entering into combination with a great variety of other substances, quite the opposite is true of nitrogen and argon. These gases serve to dilute the oxygen of the air, but they remain unchanged under most circumstances. Certain compounds of nitrogen are of great importance, however. The living substance of plants and animals contains nitrogen compounds, and these compounds are essential constituents of the food of all living things.

CHAPTER X

RELATION OF AIR TO FOOD MANUFACTURE

126. Questions for discussion. 1. When bread is burned in baking there has usually been no flame, and the bread has not been consumed as would be true if it were burned in a furnace. What has really happened to the food? What is the black substance produced, and what is its origin? 2. What plants are the principal sources of commercial starch? 3. What plants are the principal sources of commercial sugar? 4. In what countries is most of the world's sugar produced?

5. How do you account for the yellowish color of a growing wheat field after several cloudy days? 6. Why do most plants grow slowly in the shade? 7. Why do leaves of most land plants die if submerged in water? 8. Can you suggest any way in which dust, for example from roadways or cement works, might injure leaves? 9. What change do green plants produce in the earth's atmosphere? If there were no green plants, would the air probably remain suitable for man's use?

10. Are carnivorous animals in any way dependent upon plants? 11. If we were to fill our sleeping-rooms with growing plants, would they contribute to the oxygen supply of the air at night? 12. What plants do you know that grow without contact with the soil? 13. What makes the stalks of celery white? 14. If plants are the source of all foods, how do they secure their own food?

127. Sources of our food. A large part of our food consists of plants or parts of plants (such as fruits and vegetables) that are eaten in almost or quite the natural condition. Such substances as flour and sugar are manufactured from plants. Of course in all these cases there can be no doubt that our food comes directly from plants. Another important class of food materials includes meats and other animal products. The animals feed upon plants, and thus there are only one or two stages before we come back to plants as the source of our food. The more we think of this, the more fully we shall be convinced that almost



FIG. 60. Forests, orchards, and fields of grain growing from dead soil and from dead air
The air and soil are the sources of materials for the vegetation of the earth

all the things that we eat come directly or indirectly from plants. The next question is, How do plants produce these food materials?

128. Sources of plant materials. Before we can solve the problem of where the plant gets its materials we must know what these materials are. It must be understood that the substance of which a plant is composed is not a simple substance, or element, such as those described in the preceding chapter, but a compound or number of compounds. In order to learn what elements are present in these compounds it is necessary to decompose them. Fortunately this is easily done.

If a bit of dry wood or other plant product, such as starch, is placed in a test tube and heated, it will be discovered that some material is driven off in the form of a gas, and that a black substance remains in the test tube (fig. 61). This black substance is carbon. Carbon composes a very large part of the plant. Water will also be found on the inside of the tube near the mouth. We may therefore conclude that when the compounds making up wood are decomposed, the principal substances resulting are carbon and water. What is the source of the carbon?

There is often some carbon in soils, especially the black loam soils, but there may be none in such soils as clay or sand, yet plants grow very successfully in soils with no carbon. The plants do not take from the soil much material except water. There is only one other possible source for the carbon used by plants, and that is the air. If you will recall the facts regarding the composition of the air, you will remember that the atmosphere contains a small amount of carbon dioxide.

While plants may grow very well in a soil containing no car-



FIG. 61. Decomposition of starch

When starch is decomposed by heat, a black deposit of carbon remains in the bottom of the tube, and water condenses on the inside of the tube



FIG. 62A. A field of corn being harvested



FIG. 62B. A field of ripe wheat

What are the raw materials used in the two world food factories shown on this page?

bon, they are not able to grow in an inclosed space supplied with an atmosphere from which the carbon dioxide has been removed. We conclude, therefore, that the air is the source of the carbon used by plants.

It remains for us to discover how plants secure carbon dioxide from the air and how they make from it and water the compounds which they need for food.

129. Food of plants. The food materials of plants are not very different from those of animals. For instance, starch and sugar are very common in our own food, and they are also an important part of the food of our common plants. The difference between the food habits of common plants and those of animals is not so much in the sort of things that they require as in the way in which they secure these things. The animal secures the starch, sugar, and other compounds from a plant or from some other source where they may be found in such condition that it can use them directly (fig. 62). The plant, on the other hand, is able to make these compounds from very simple substances.

Such compounds as starch and sugar are composed of three simple substances—carbon, hydrogen, and oxygen. We can easily prove that this is the composition of starch by heating some in a test tube, as in the case of wood (Sect. 128). The heat decomposes the starch, and we have carbon and water. Water, we already know, is composed of hydrogen and oxygen, and therefore we have here the three substances.

130. The place where food is made. If a green leaf is examined early in the morning, little or no sugar or starch will be found in it. After several hours' exposure to sunshine, however, sugar and starch will be abundant in the leaf, and the quantity will increase with longer exposure to the sun's rays. Sugar is made in the leaf from carbon dioxide and water and converted into starch for storage. Under the influence of sunshine this manufacture may go on in any green part of the plant. Since the leaves are the principal green parts of plants, it is in the leaves that most of the sugar-making is carried on. Sugar may be used as food by the leaf or stored in the leaf after being

changed into starch, or may be transferred to other parts of the plant where it is used or stored as starch until it is needed by the plant.

131. Some problems. We shall now want to know how the carbon dioxide gets into the leaf, how the water gets

there, what chemical changes take place, and what the light does in this process. We shall have to learn certain things about the structure of the leaf, and we shall therefore next study this organ, which is the food factory of the world.

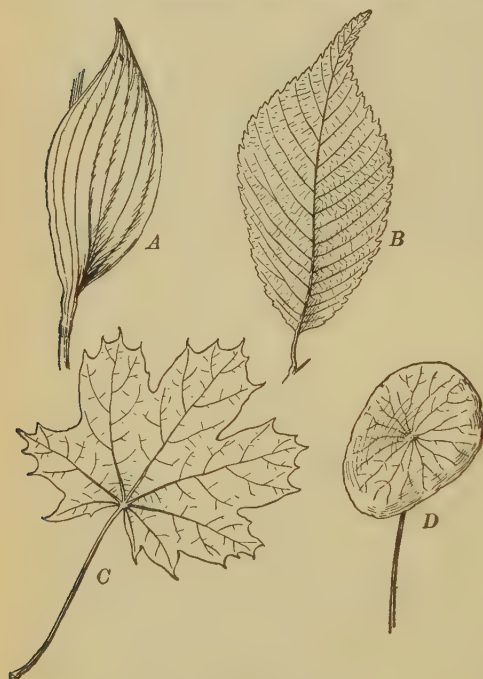


FIG. 63. Types of leaves

A, leaf of the lady's-slipper orchid; B, leaf of the elm; C, leaf of the maple; D, leaf of the water shield

132. Structure of leaves. The most conspicuous part of the ordinary leaf is broad, thin, and green and is known as the blade. Besides the blade there is usually a stalk, called the petiole, and sometimes also, at the base of the petiole, two little blades, which are called stipules. The petiole is rather strong and woody and serves to hold the leaf blade in the proper position (fig. 63).

The leaf contains many veins, which serve as a framework to support it as well as for other purposes. In many leaves there is a main vein extending from the petiole toward the tip of the

blade; smaller veins branch out from this and extend obliquely toward the edge. Other leaves, like those of the geranium or nasturtium, have no single central vein, but, instead, several large veins extend outward like a fan from the end of the petiole. There are other leaves, like that of the common plantain, in which the principal veins all start from the petiole and run nearly parallel toward the tip of the blade. The surface layer of the leaf is like a thin skin and is called the epidermis. The green part of the leaf inside the epidermis is the mesophyll. The epidermis is ordinarily thinner than fine tissue paper and as transparent. It can be quite easily peeled from some leaves, while on others it is too delicate to be removed. The epidermis is found on petioles and young stems, as well as on the blades.

Although it is so thin the epidermis is able to protect the mesophyll. If it is removed, the lightest touch seems to crush the mesophyll, and within a few minutes it will begin to shrivel from loss of water. If the epidermis were not present, the mesophyll would soon be destroyed by exposure to the air.

133. Structure of the epidermis. It is very plain as you peel it off that the epidermis covers the entire blade, and it is equally certain that air gets into the leaf in some way. Just how it gets in is to be explained by examining the structure of the epidermis, and this must be done with the microscope, for the unaided eye gives little information on this point.

If a bit of the epidermis from the leaf of a lily, a blue flag, or a narcissus is examined with a high-power microscope, it will be found that it looks something like a brick pavement (fig. 64). It is made up of many small oblong bodies closely joined together. These bodies are like bricks only in shape and in the way they are joined. They are called cells, and not only the epidermis but also all the other parts of the plant are made up of cells. Unlike the bricks of a pavement with which we compared them, the cells are transparent, and, so far as can be seen in the piece of epidermis, they are hollow. The cells contain the living material of the plant, though this is often

so transparent that it is difficult to see. Ordinarily we see only the wall which incloses the living part of the cell.

A few of the cells of the epidermis are crescent-shaped or bean-shaped instead of rectangular. These cells are always in pairs, with their concave surfaces next to each other. These curved surfaces do not come tightly together, as the surfaces of all the other cells do, and this leaves a little space between them which is an opening through the epidermis. These openings are called stomata, and the two bean-shaped cells around each opening are called the guard cells. The guard cells make the opening larger or smaller by changing their shape.

If you look into the microscope, the stomata seem to be far apart, but one must remember that the view in the instrument is very much magnified. Perhaps half a dozen stomata are seen, apparently much scattered over a wide surface, but in reality the part of the epidermis seen under a high-power microscope is not larger than the period at the end of a sentence. It is common for leaves to have more than 60,000 stomata to the square inch, and some leaves have as many as 700,000 per square inch. Most of these are found on the lower surface. It has been estimated that a large sunflower leaf may contain 13,000,000 stomata. This great number allows the carbon dioxide to enter freely and much water vapor to escape.

The cells of the epidermis are not always so regular in shape as in the lily. In very many plants they are extremely irregular, though always fitting together very closely. The stomata, too, vary in shape and appearance.

134. Structure of the leaf interior. The interior, or mesophyll, of the leaf (fig. 64), like the epidermis and all the other parts of a plant, is made up of cells. Each cell has a thin, transparent wall and includes a semi-liquid, clear mass of living substance (protoplasm), and a number of green granules called chloroplasts. The irregular cells near the lower epidermis have large spaces between them and are called the spongy tissue. Its many spaces give the air which enters through the lower epidermis an opportunity to reach all the cells.

The upper green cells are long, narrow, and cylindrical. They stand side by side, with the end of each cell toward the epidermis, and are called the palisade tissue.

The green coloring matter, or chlorophyll, does not color the cells green throughout, as one might suppose. In each cell there are found some small, rounded grains, the chloroplasts, which are bright green in color, but the remainder of the cell is quite colorless. The chlorophyll may be removed from the chloroplasts by the use of alcohol, leaving the leaf white. These chloroplasts are much more numerous in the cells of the palisade tissue than in those of the spongy tissue, so that the upper side of a leaf is usually much darker green than the lower side. It is upon these chloroplasts that the light acts in the manufacture of substances which finally are recognized as sugar and starch.

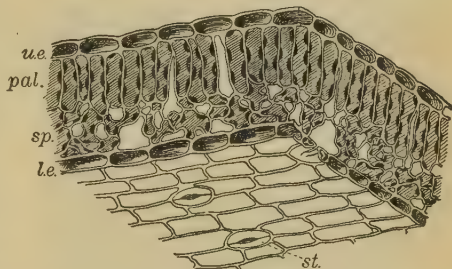


FIG. 64. Diagram of a leaf section

The view shows a part of a leaf, greatly magnified. The lower surface and the cut edge are represented: *u.e.*, upper epidermis; *pal.*, palisade tissue; *sp.*, spongy tissue; *l.e.*, lower epidermis; *st.*, stoma

135. Entrance of materials into the leaf. Water, which has been absorbed from the soil by the roots, passes up through the stem and reaches the various parts of the leaf through the leaf veins. Those cells which are not in contact with the veins receive water through other cells. The water supply therefore reaches every cell of the leaf.

Carbon dioxide, as well as other components of the air, passes through the stomata by diffusion. The spaces between the cells of the inside of the leaf allow the gas to spread throughout the leaf. In this way carbon dioxide and water—the raw materials of food manufacture—are brought together in the cells of the mesophyll.

136. Manufacture of carbohydrates. It is in the cells within the leaf that a change occurs in the two compounds, water and carbon dioxide, by which sugar is produced and oxygen released.

If the sugar is not needed at once as food for the plant, it may be converted into starch and stored in the leaf to be used during the night, when the plant cannot manufacture food. A part of the sugar is changed into cellulose, which makes up the



FIG. 65. No fresh soil for eighteen years

This rubber plant has grown from a small branch which eighteen years ago was placed in this metal tub. During these years the soil was not changed. New supplies of food materials have come from the air and water

woody fibers which form the supporting skeleton of the plant. It is convenient to group under the name "carbohydrates" sugar and such substances as starch and cellulose, which are easily produced from sugar by the plant.

137. The waste material. The oxygen produced when sugar is formed is gaseous oxygen exactly like that in the air, and may pass out through the stomata into the air, where it mingles with the other gases. It

may be called the waste material of the process of manufacture which we have just been studying. Bubbles of oxygen may often be seen rising from plants which are growing under water. It is escaping from land plants in a similar way, though it is not visible in the air. Some of this same oxygen may be used by the plant in its respiration.

138. The source of energy. A factory needs energy, and our carbohydrate factory in the leaf must have energy to operate it. Most factories that we are familiar with are operated by energy derived from a waterfall, or from burning coal under

the boilers of a steam engine, or by electric power, but the leaf derives its energy from a source that is different from all these and at first appears rather surprising—the sunlight. Light is as much a source of power as is electricity, heat, or falling water, but men have not yet learned so well how to use it. We may cause light to do work on a photographic plate, we know that it will change the colors of the chemicals we use to dye our fabrics, but we have not learned how to make it run our factories. The leaf is able to use this energy of light in the manufacture of carbohydrates. If there is no strong light upon the plant, it is not able to carry on this work, and the factory stops. For that reason all green plants must live where there is light. They cannot make starch or sugar at night. Artificial light will answer if it is strong enough, but usually it is too weak to have any appreciable effect.

Plants secure carbon dioxide from the air; they secure water and substances in solution in water from the soil. The supply of carbon dioxide is greatly in excess of the plant's needs. Although soil water and the needed soil substances may often be quite limited, plants sometimes exhibit the ability to grow for very long periods in small quantities of soil (fig. 65). They cannot do this without adequate light.



FIG. 66. Indian pipe—a dependent flowering plant

This plant is wholly without chlorophyll; it secures its food from organic substances in the soil

139. Dependence upon chlorophyll. When we gain new ideas we need new names for them just as we need new names to label new human acquaintances. This section summarizes recently acquired ideas as well as the new terms by which they are known. It follows from what has been said in the preceding sections that the carbohydrate manufacture can go on only in



FIG. 67. A common toadstool—a saprophytic plant

This mushroom grows upon decaying plant and animal materials

the presence of light and chlorophyll. This fact causes us to regard chlorophyll as a very important substance. All plants which have chlorophyll are able to manufacture their own food, while plants which do not (figs. 67 and 68) have it are obliged to depend upon securing the food already made. We may call those plants which have chlorophyll independent plants and those which do not have it dependent plants.

The process in which the chloroplasts of green plants, with the aid of light, manufacture carbohydrates out of water and carbon dioxide is called photosynthesis. This is the name of the process we have been studying.

140. Sugar and starch in the leaf. Sugar is commonly formed in the leaf during the day by the process of photosynthesis and is being continually carried away for use in other parts of the plant. On a bright, sunny day it is made much more rapidly than it can be carried away or used. If there were not some way to dispose of it, the sugar would accumulate in the leaf until the sap became so filled with it that the work of the leaf could not go on. The leaf has the power of changing the excess sugar into starch. This removes the excess carbohydrate from the sap, since starch is not readily dissolved in water. By evening, if the day has been a bright one, a great deal of starch is stored in the leaf. At night, when no sugar is being made, the starch in the leaf is slowly changed back into sugar. Some of it is used as food for the leaf and some is carried



FIG. 68. Corn smut—a parasitic plant

This parasite grows in the corn plant and produces masses of dark spores which may appear on the ear, stalk, or leaves of the corn

away to serve as food in other parts of the plant, to be stored more permanently as starch in seeds or roots, or to be converted into cellulose in the woody stem.

The facts just related assist in explaining how it is that plants often grow more rapidly at night than during the day. While the food is not being made during the night, it is being carried from the leaves to other parts and used even more rapidly than during the day.



FIG. 69. Making plants into beef and milk

A herd of Hereford cattle which have enjoyed good pasture lands

141. Comparison with a factory. The process of photosynthesis has been likened to the work of a factory. It may be interesting to sum up this activity of the plant by use of the following comparison:

The factory	Green part of the plant
Machinery	Chloroplasts
Energy	Light
Raw material	Water and carbon dioxide
Finished product	Carbohydrates
Waste product	Oxygen

142. Importance of green plants. The food supply of all living things depends upon the work of green plants. Carbohydrates, fats, and proteins make up a very large part of our own food and of the food of many animals. Animals are unable to construct these foods from simple compounds. Cattle eat grass

and grain and make them over into their own flesh (fig. 69), but they are unable to use the very simple substances—carbon dioxide, water, and nitrate—in the way in which they are used by the plants. The green plants and the work which they do are therefore indispensable in making the food of the world.

143. Manufacture of fat. Although the carbohydrates form a large part of all plants, they are by no means the only substances manufactured by plant cells. We are all familiar with such fats as olive oil, cottonseed oil, and corn oil. Most plants produce such substances and store them in their seeds. Like the carbohydrates the fats contain only carbon, hydrogen, and oxygen and are undoubtedly produced from the carbon dioxide of the air and water. We do not know as yet all the details of how the plant does this.

✓**144. Manufacture of protein.** A third group of substances of great importance which are constructed by plants are the proteins. In addition to carbon, hydrogen, and oxygen, all proteins contain nitrogen and also a small amount of sulphur. Most of the carbon, hydrogen, and oxygen are obtained from carbon dioxide and water, but the plant cannot secure its nitrogen from the air. The plant uses nitrogen from such compounds as ammonia and nitrates. These are present in good soils and are often added to poor soils as fertilizer. Animals are as unable to make protein from simple substances as they are to make carbohydrates.

PART II. WATER AND ITS USES

CHAPTER XI

ICE, WATER, AND STEAM

145. Questions for discussion. 1. One's breath can usually be seen in cold air and not in warm air. Why? 2. How hot is boiling water? 3. Can you heat it hotter than the boiling point? 4. Campers on high mountains sometimes experience difficulty in cooking food. Why? 5. By what methods can foods be cooked in such places? 6. Can water be made to boil at less than $100^{\circ}\text{C}.$?

7. Will fresh water and water saturated with salt or sugar boil at the same temperatures? 8. In cooking potatoes by boiling, can the time of cooking be materially shortened by using a hotter fire after the boiling has started? 9. Will potatoes cook more quickly in a cooker with a high-air pressure? 10. May there be evaporation from a snow bank during cold weather?

11. How does a thermos bottle keep hot things hot, and cold things cold? 12. What advantages from cold-storage plants have resulted to city populations? to country populations? 13. Why are your feet colder when you are standing in melting snow than when you are standing in freezing snow?

146. When water freezes. Is ice water? Is snow water? What happens when water freezes? When water gets cold enough it becomes solid, and as it becomes solid it may break the containing vessel. It will be found extremely interesting to watch water in the process of freezing. At what temperature does water freeze? Is the temperature at which water freezes really the same for both centigrade and Fahrenheit thermometers?

If a quantity of water in liquid form is cooled slowly, it will be found that as it cools it contracts. Perhaps that is as we

should have expected, since most substances contract when cooling. As the water approaches the freezing point, however, it begins to expand at 4°C . (or 39.2°F .), and when frozen has expanded more than the whole amount it contracted in cooling. After it has become solid, if it is cooled still more it again contracts, but when frozen it never contracts to so small a volume as it had when it was liquid.

See if you can determine for yourselves the temperature at which water begins to expand and that at which it freezes. Are these temperatures the same for milk (fig. 70)?

The temperature during freezing behaves almost as peculiarly as does the volume. If the thermometer is observed during the experiment, it will be found that the temperature falls regularly until the water begins to freeze; it then remains stationary until all the water is frozen, after which it begins to fall again. If a substance (salt or sugar, for instance) is dissolved in the water, the freezing point is much lower—just how much lower depends upon the substance used and the amount of it dissolved.

147. Changing water to steam. When water is heated over a lamp or a stove, it gets so hot that some of the water nearest the flame (that is, at the bottom) is changed to steam. The steam rises in bubbles through the remaining water, and the bubbles burst at the surface. This action is called boiling (fig. 71).

The temperature at which boiling begins is called the boiling point. On the centigrade scale this is 100° . What is it on the Fahrenheit scale? After a mass of water has reached the boiling point, its temperature does not rise further as long as any of the



FIG. 70. A frozen bottle of milk

Milk, which is mostly water, expands when it freezes

water remains in the liquid form. In your experiment you will find the boiling point somewhere near 100°C ., but it is not probable that it will be exactly that, owing to variations in elevation and air pressure, as discussed in the next section. The

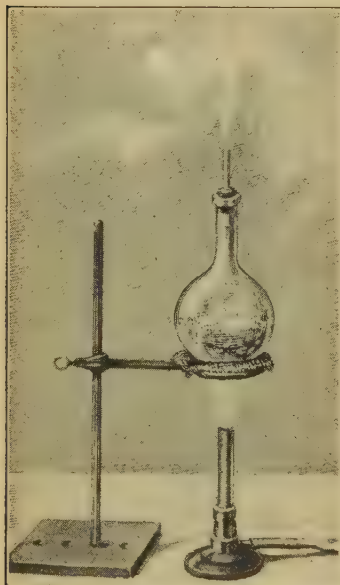


FIG. 71. How water boils

Note the bubbles rising through the water and the steam issuing from the tube. The steam is transparent when it is in the flask and also as it issues from the end of the tube

boiling point is raised if solid substances such as salt or sugar are dissolved in the water.

When we wish to be sure that foods are not heated above 100° during cooking, we often cook them in a steamer or double boiler so that they shall get no heat except through the boiling water; this prevents burning.

148. Air pressure and the boiling point. The boiling point is affected by changes in air pressure. If the air pressure is 30 inches on the barometer, the boiling point of pure water will be 100°C .; if the pressure is greater, the boiling point will be higher; and if the pressure is lower, water will boil before it is as hot as 100°C . To most of us this makes little difference, but to the people who live on the mountains it is sometimes a serious matter. In elevated

places the air pressure is less than that near the sea level, and the boiling point is lower. On the top of Mont Blanc the boiling point of water is only 84°C ., at the city of Quito, Ecuador, it is 90°C ., and at many places in our own country the same condition exists (fig. 72). When you boil eggs or potatoes, it is the heat and not the boiling that cooks them. If you cannot get water hotter than 90°C ., for instance, it will take very much

longer to cook food materials; and if the temperature is too low, it may be quite impossible to cook certain foods. This, of course, applies only to those foods that are cooked in boiling water.

Increased pressure raises the boiling point very decidedly. In the steam boiler, where steam is not allowed to escape until it has reached a high pressure, the pressure of the steam has the same effect upon the boiling point as does the increased pressure



FIG. 72. Boiling points at different heights

Mount Rainier, Washington. The figures show boiling points (Fahrenheit scale) at different elevations when the air pressure is thirty inches at sea level

of the atmosphere. The boiling point under additional pressure of 30 pounds to the square inch is 120.6°C. , at 100 pounds it is 155°C. , and at 300 pounds it is 180°C.

The steam cooker, now in common use, has been designed to take advantage of the rise of boiling temperature with increased pressure. The cooker is usually a strong metal vessel in the form of a cylinder with a lid that can be fastened down very tightly. This lid is provided with an escape cock, a pressure gauge, a thermometer, and a safety valve. The safety valve is usually set to be released if the pressure rises to more than thirty pounds. A small amount of water is placed in the

bottom of the cooker, the top is fastened on tightly, and heat is applied. Since the steam formed is not allowed to escape, the pressure increases and, correspondingly, the temperature shown by the thermometer rises. If the heating is continued, the temperature will rise to about 120°C . (248°F .) before the safety valve begins to allow steam to escape. By regulating the amount of heat applied the temperature may be kept at any point between 212° and 248°F . This appliance makes it possible to cook by boiling on mountains. At lower elevations it is valuable because it enables us to cook foods at high temperatures, and also shortens the time of cooking. Such a device is also useful in the destruction of bacteria.

149. Expansion of steam. When water changes into steam, it increases in volume if it is free to expand. This increase may be sudden and very great. Steam at atmospheric pressure may occupy about sixteen hundred times as much space as the liquid water from which it was formed. Since steam may occupy so much more space than water, a similar volume of it is correspondingly lighter. It is in fact lighter than a similar volume of pure air. If water is boiled in a closed vessel (as in a steam boiler), the steam cannot expand; but as the temperature increases, the pressure also increases, and finally the steam finds some way of escape. This may be by breaking the boiler or through some means provided for its escape, as through a safety valve. This power of expansion is utilized in the steam engine.

150. Steam a gas. Steam is a transparent, colorless gas. When steam escapes into the air, there is always a white cloud. This cloud is not steam, but has been formed from steam. The steam quickly cools to a temperature near that of the air, and this is so much below the boiling point that the steam returns to the liquid form. The white cloud is made up of many small drops of liquid water.

It may be observed that the steam which emerges from a teakettle in which water is boiling is transparent as it passes from the end of the spout. In this transparent area the steam is not yet condensed (fig. 71).

151. Solids, liquids, and gases. In previous discussions we have seen that the same substance may occur in solid, liquid, or gaseous form. This is noticed more frequently in the case of water than with any other common substance, but it will be worth while, in the following study of water, to remember that many of the things which are true of it are true of other substances also. We need to be clear about the names which are used for the different states of water. The liquid form is most commonly found, and to this form the name "water" is especially applied. It must be remembered that when liquid water evaporates (thus passing into the form of gas) or when it freezes (becoming a solid), it does not cease to be water. For instance, although the water contained in the air is a gas, usually called water vapor, we may speak of it as water; and when water is a solid we call it ice; but it is water whatever its form may be.

152. Distillation. Formerly it was customary for ships to carry with them enough fresh water to last throughout the voyage. Some steamships now prepare their daily water supply from the salt ocean water by distillation. When water containing salt or other solid substance is boiled and thus evaporated, the solid does not evaporate. The steam does not contain the impurity, and it may therefore condense into pure water. This process is called distillation. This is the most certain method of securing pure water (fig. 73).

Large distilling plants are employed to produce commercial supplies of pure water for drinking-purposes, for ice manufacture, and for other uses. In private establishments and in laboratories smaller plants are sometimes maintained. It is easy to prepare a simple device for distilling water in the laboratory.

153. Boiling point and candy-making. The fact that sugar dissolved in water raises the boiling point has an interesting application in candy-making. Starting with a relatively weak sirup, we boil it until the evaporation of water has concentrated the sirup sufficiently to produce the kind of candy desired. The rise of the boiling point indicates the density of the sirup.

Dependable results can be secured by using a thermometer. Temperatures at which boiling should stop are as follows:

	CENTIGRADE	FAHRENHEIT
For fudge and similar candies	115°	240°
For taffy and pulled candies	149°	300°
For peanut brittle	154°	310°

154. Boiling and melting points. Every substance has its boiling and melting points, but these may be at temperatures very different from those of water. The approximate melting and boiling points of a few substances are given below:

	MELTING POINT IN DEGREES C	BOILING POINT IN DEGREES C
Air		-185.0
Alcohol	-130.5	78.0
Ammonia	-77.0	-33.0
Benzene	5.4	80.4
Carbon dioxide	-78.0	-57.0
Cast iron	1200.0	
Copper	1083.0	2100.0
Ether	-117.0	35.5
Hydrogen	-259.0	-252.0
Lead	327.0	1525.0
Paraffin	55.0	400.0
Platinum	1755.0	2450.0
Sulphur	114.0	445.5
Water	0.0	100.0

Excepting for differences in temperature, most substances behave very much like water in changing from solid to liquid and from liquid to gaseous condition. Few of these substances expand at the time of freezing, as does water, and these few expand much less.

Substances such as glass and wax do not have a clearly defined melting point. They gradually soften, becoming first like a very thick liquid, and finally flow freely.

155. Evaporation. Water will slowly change into vapor (evaporate) at any temperature. When the temperature of water is not high enough to cause it to boil, the water changes into vapor, but not rapidly. This is shown by the drying of wet objects when exposed to the air. Even if water is frozen, evaporation continues. This is shown when wet clothing is

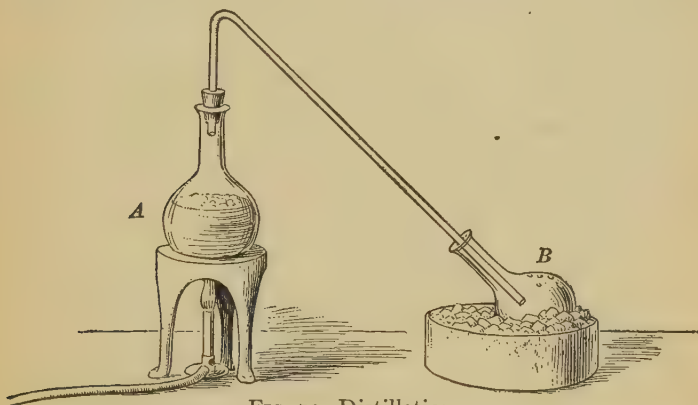


FIG. 73. Distillation

The solution to be distilled is placed in *A*; the steam which passes through the tube is condensed in *B*, which may be cooled with ice or snow

hung out of doors on a cold day. It immediately freezes and remains frozen until it has become dry by evaporation of the frozen water.

The rate of evaporation depends upon several factors. For instance, it is commonly known that things dry more rapidly when the air is warm than when it is cold and that drying is assisted by wind. Rapid evaporation is favored by high temperature, dry air, winds, and large exposed surfaces.

156. Heat used in boiling and evaporation. When water boils, considerable quantities of heat are used. If heat is supplied more rapidly, it results in the more rapid formation of steam, but there is no change in temperature of either the water or the steam. At the end of half an hour's vigorous boiling, a kettle of water will have the same temperature as at the begin-

ning of the period, but the amount of water in the kettle will have decreased. The effect of the heat, therefore, has been to evaporate the water, but it has had no effect upon the temperature. The fire or stove has lost the heat which has passed into the water.

The total amount of heat that disappears when a gram weight of water changes into steam is the same whether the steam forms rapidly, as in boiling, or slowly, as in evaporating from wet clothing. In the latter case there is usually no source of intense heat, such as the fire, and the heat which disappears during evaporation is taken from the water itself and from the surrounding objects. Since heat disappears from the water and its surroundings, they are cooler (fig. 41, p. 63). In the case of a bather standing on the beach in a wet bathing-suit, the heat which is used in evaporating the water from the wet bathing-suit is taken from the water remaining in the suit and from the body of the bather, thus giving him the sensation of cold (fig. 40, p. 61). As soon as all the water evaporates from the suit this withdrawal of heat ceases and the surrounding air temperature is felt.

157. Evaporation and drinking-water. In many hot dry countries the water from wells is usually warm and needs cooling if it is to be used for drinking. Often ice cannot be had, and other methods of cooling must be adopted. The water is put into porous earthenware jars or into canvas bags, and these are placed where the dry winds can blow over them. The water soaks through the canvas or the porous jar and evaporates so rapidly in the dry, hot air that the contents of the vessel are made pleasantly cool. Travelers in such regions have learned to cover their canteens with layers of woolen cloth and to wet this at every possible opportunity. So long as the cloth cover is wet, the water in the canteen will be kept cool enough to be palatable. In many parts of the South where ice is expensive iceless coolers are used which work on this same principle. A container fitted with convenient shelves is covered with cloth which dips into a pan of water on top of

the cage. By this device the entire surface of the cloth is kept wet, and the evaporation keeps the air in the container cool.

158. Ice machines and cold storage. Cooling by evaporation is applied in a practical way for the artificial production of ice and in cold-storage plants. In the operation of these plants advantage is taken of the fact that the boiling point of ammonia gas at atmospheric pressure (-28° F. or -33° C.) is so little below atmospheric temperature that the boiling point can be raised above the usual temperature of the air by increase of pressure (Sect. 148). Thus, while the boiling

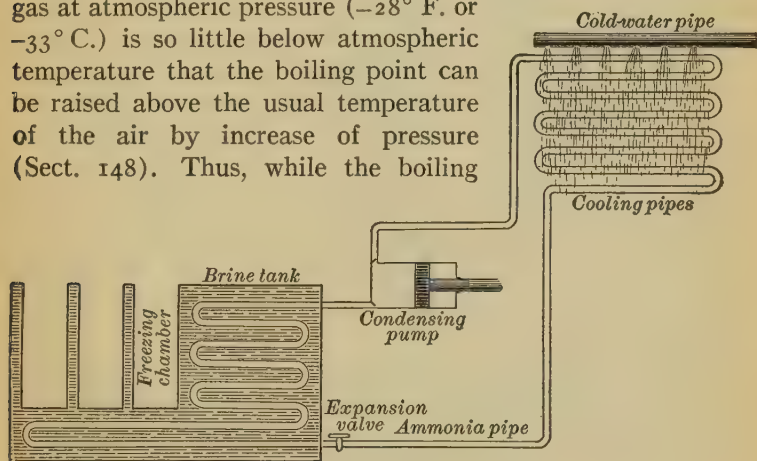


FIG. 74. An artificial-ice machine

point is -28° F. at atmospheric pressure (14.7 pounds), it is raised to 80° F. by a pressure of 155 pounds to the square inch.

Figure 74 represents the essential features of an ice-manufacturing plant. The condensing pump forces the gaseous ammonia into the pipes to the right with a pressure of at least 155 pounds to the square inch, and the gas is cooled to the necessary degree by the water which flows over the cooling pipes. The gas therefore condenses into a liquid. This liquid ammonia is allowed to escape through the valve into the pipes at the left only as rapidly as the excess is removed by the pump, and the pressure in these pipes therefore never rises much above 30 pounds to the square inch. The liquid which has escaped into this place of lower pressure immediately begins to change

into a gas and, in so doing, absorbs heat from its surroundings. The pipes into which the liquid ammonia expands are usually surrounded with brine, and this is cooled by the evaporating ammonia several degrees below the freezing point of water. The brine, in turn, cools the water which has been placed in the freezing-chambers, three of which are shown at the left of the diagram (fig. 74). The gaseous ammonia passes on to the pump and is used again.

In cold-storage plants the machinery is similar to that used in making ice, but it is used to cool rooms instead of to cool vessels of water. Any reasonable degree of cold may be secured by proper construction and operation of the machine. It is thus possible to store each kind of food in the particular temperature that is best suited to it (fig. 75). In meat and fish markets brine pipes are often carried along the counters where perishable food is displayed. The cool air, being heavy, does not mix with the air of the store by convection currents. The brine pipes are often white with frost. Why?

Cold storage has made possible a supply of fresh foods at seasons when they could not otherwise be obtained. Cold storage has brought the fruits of the tropics to the door of every modern home. It has lengthened seasons almost at the will of the shipper. Cold storage has made the foods from all parts of the earth and of all seasons available, at least in the cities, at all times of the year.

159. The principle of the refrigerator. As water in freezing does not change temperature until all of it is frozen, so when ice melts, it does not get warmer than 0°C . until all the ice is melted. The heat necessary to melt it is taken from surrounding objects, and so they are cooled as long as the ice is melting. It is on this principle that refrigerators work. In order to economize as much as possible in the use of ice, the walls of the refrigerator are packed with substances through which heat does not easily pass. If the refrigerator is not well built in this particular, so much heat comes into it from the outside that the ice does not lower the temperature in the box very much, and the

ice is more rapidly consumed. If a twenty-five pound piece of ice is placed in one refrigerator or in an ordinary wooden box, and the same amount in another refrigerator, and records are kept showing the length of time required for both pieces of ice to melt, an interesting demonstration will be provided regarding the efficiency of refrigerators.

160. Some freezing-mixtures. Common salt, as prepared for household uses, and some other substances absorb moisture very readily. Salt absorbs it so readily that when the humidity of the air is rather high, it absorbs water even from the air and becomes wet, as all of us have had occasion to notice when using a salt shaker in damp weather. Salt not only absorbs gaseous water from the air but also absorbs water from a piece of ice, changing the solid ice to liquid water in absorbing it. This explains why salt is used to melt ice on sidewalks and in other places.

When ice is melted, heat is required to carry on the process. When salt melts ice, the source of heat is the ice and the surrounding air or other objects. If salt and ice are well mixed, the ice will be melted rapidly by the salt, but the temperature of the mixture will not remain at 0°C . It will fall to -17°C . or even slightly lower. The heat needed is taken from the mixture itself, and the presence of the salt prevents the water from freezing at the lower temperature, as it otherwise would do.



FIG. 75. Within the cold-storage room

In such rooms meat may be kept frozen and perfectly preserved as long as is desired

Such a freezing-mixture of salt and ice is often used to produce a temperature slightly below 0°C ., as in freezing ice cream.

161. Amount of water evaporated by the air. When we consider that the oceans, lakes, and rivers make up the larger part of the surface of the earth, and that water is evaporating from this surface all the time, it is plain that a very large amount of water evaporates. How much it is no one knows exactly, but

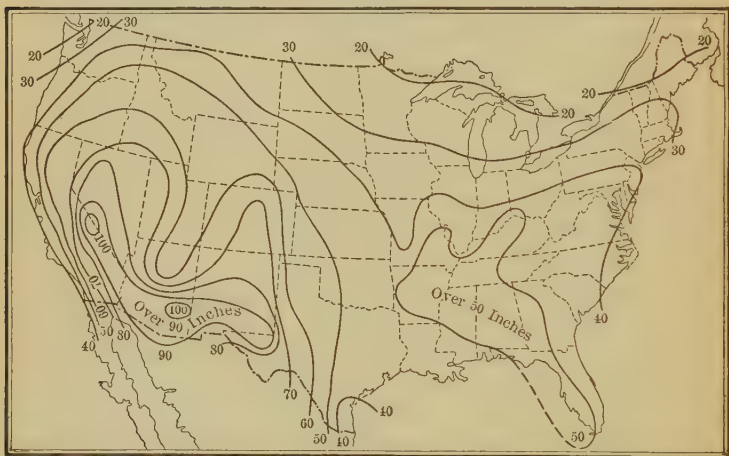


FIG. 76. Rate of evaporation in the United States

The map shows the estimated rate of evaporation in inches per annum. Note the great differences between different parts of the country

we get some idea when we remember that all the water that falls as rain or snow has evaporated from the ocean or from the land. It is obvious that water which falls as rain or snow may evaporate without first flowing to the oceans or lakes.

A study has been made of the rate of evaporation in the United States (fig. 76). It is believed that about 30 inches of water evaporates each year from the surface of Lake Michigan and about 70 inches from Great Salt Lake. In some of the desert regions of the Southwest perhaps as much as 100 inches would evaporate annually if there were any body of water there.

162. Evaporation from plants—transpiration. The evaporation of water from land is greatly affected by plants. Trees, grasses, weeds, cultivated crops—in fact, all common land plants—absorb water from the soil; and, as a rule, most of this water will, sooner or later, evaporate from the leaves.

Usually we are not aware that water is evaporating from the leaves of plants, since it passes off as a gas and is therefore not visible. A demonstration of its presence may be made by inclosing several leaves in a bottle (fig. 77) in such a way that there is little chance for water to enter or leave the bottle except through the leaves. The water given off from the leaves soon saturates the space in the bottle, and the excess is deposited on the inside of the bottle. If the leaves are removed from the plant they should be placed with their lower ends in water.

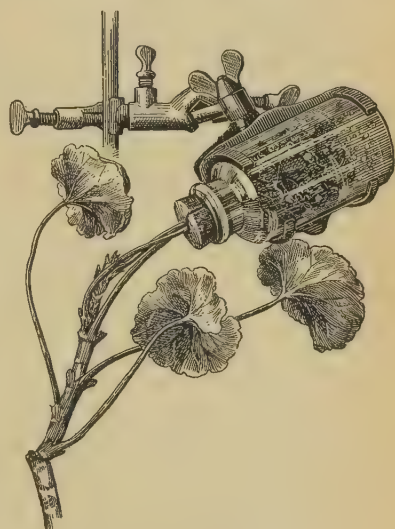


FIG. 77. Transpiration by leaves

Some of the water which evaporates from the leaves condenses upon the inside of the bottle

A more satisfactory way to show the loss of water is to weigh a potted plant from time to time, having first wrapped the pot in sheet rubber. (Why?) If the area of the leaves is ascertained, it is possible to know just how much water has been evaporated per square inch in a day. It has been found that all the leaves of a good-sized sunflower plant may together evaporate as much as a quart of water daily. A large tree will evaporate from 700 to 900 pounds of water on a favorable day, and the grass on a vacant city lot may give off a ton of water in a day.

CHAPTER XII

THE WATER SUPPLY

163. Questions for discussion. 1. What is the principle of drinking through a straw? 2. A coarse towel was left hanging over the edge of a partially filled bathtub, one end of the towel extending into the water, the other end hanging outside. Water had dripped from the towel until there was a small pool on the floor. How did this take place? 3. How does a pump lift a liquid? 4. What is the difference between a force pump and a suction pump? 5. How is water picked up by a tornado on the sea?

6. Why does liquid flow from small-necked bottles with a gurgling noise? 7. Why is it difficult to pour oil into a can steadily if the funnel used fits the opening closely? Why does lifting the funnel help? 8. How is water forced to the tops of tall buildings? 9. What causes the water to flow in a wide spray from a lawn sprinkler? 10. Why does an iron ship float? 11. How can a submersible boat remain on the surface part of the time and under water part of the time? 12. Why cannot a submarine safely descend to the bottom in the deeper parts of the ocean? 13. Why are dams commonly thicker at the bottom than at the top?

14. If an object floats in water almost submerged, how would it behave in oil? in kerosene? in a gas? 15. What is the principle by means of which a balloon may rise in the air? 16. Is a dirigible balloon heavier than air? an aëroplane? 17. How rapidly can an aëroplane ascend? 18. What is the record height reached by an aëroplane? the record long-distance flight?

164. Water used in many ways. We can emphasize any one factor in our modern life so much that this factor may seem to be the most important of all. It is not easy to overemphasize the importance of water. Industries are dependent upon it in many ways. It may provide the power for the work that is to be done (fig. 78). It frequently is the medium by means of which solid substances like wood are carried through some of the

manufacturing processes. If steam power is used, water is needed for the boilers and for condensing the exhaust steam.

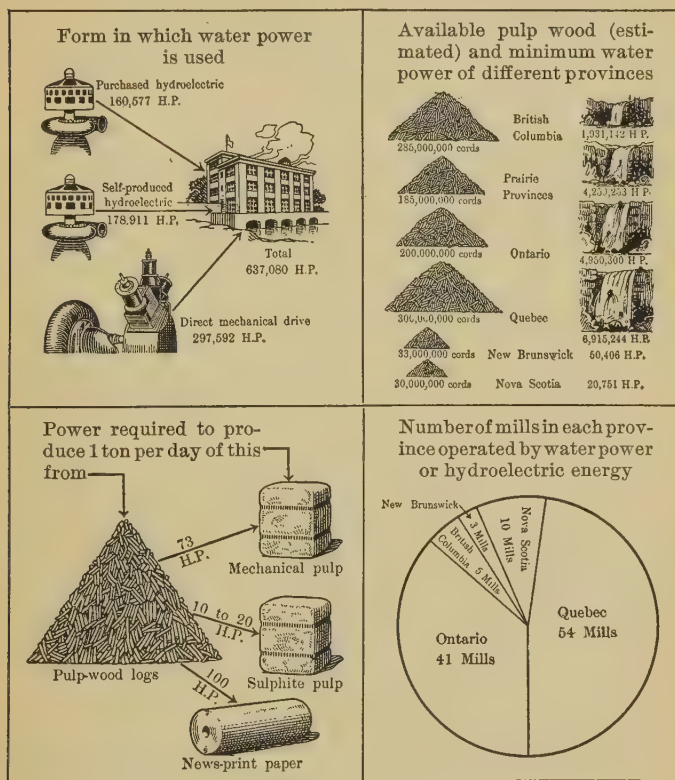


FIG. 78. Canada uses its water power in many ways

Currents of water are used to transport wood. Electric power produced by flowing water is used in the production of the pulp from which most of our paper is made. Note the cords of pulp wood handled, the quantity of horse power required, the number of mills operated

In both city and country one of the most important problems is that of securing an adequate and satisfactory supply of water. The health of the people is to a great extent dependent upon

having pure water. There must be enough good water to permit people to be clean, and to serve for drinking, cooking, laundry, and other uses. Its quality must be such that it may be used without danger. In cities often large quantities of water are needed for manufacturing and for industrial uses other than those already suggested.

165. Securing water from wells. In the country and in villages the water supply is usually from wells. In earlier times, and today in some parts of the country, natural springs are depended upon for the supply. Water is sometimes brought up from the well by means of a bucket, held by a rope or chain, but in most cases a pump is used. The pump which stands on a platform built over the well is a common sight, except in large cities. When the handle is operated, a stream of water is said to be "lifted" from the well. Do you know what a "well sweep" is? Why do not cities depend upon wells for their water supply?

166. The common pump. The structure of a pump is best learned from an examination of the pump itself or, if that is not possible, from a diagram (fig. 79). It is not difficult to make a small pump in the school laboratory. The essential part is the cylinder, which is hollow. It should usually be constructed so as to be two or three inches in diameter and possibly eight or ten inches in length. At the bottom it is connected with the pipe, sometimes called the suction pipe, which extends down into the water in the well, and at the top with a pipe leading to the spout, or the spout may be connected directly with the cylinder. At the bottom of the cylinder, over the opening leading to the pipe, there is a valve so constructed as to allow the water to pass upward but not downward. In the cylinder there is a tightly fitting piston which may move up and down. In the piston there is another valve which allows the passage of the water upward. Other parts (for example, the handle) may be added for convenience, leverage, and ease of operation, but the parts mentioned above are the really essential ones of the pump. Why does the handle make it easier to operate the pump?

As to the operation of the pump, let us assume that at the start the cylinder and pipe to the well are filled with water and that the piston is at the top of the cylinder. If the piston is pushed downward, the valve in it will permit the water in

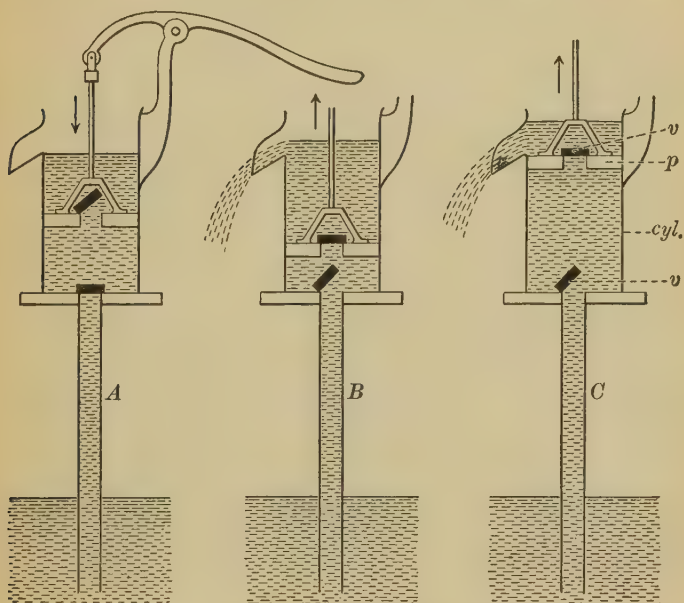


FIG. 79. The lift pump

Three stages of the stroke of the pump are shown: *A*, down stroke; *B*, up stroke; *C*, completion of the stroke. By noting the position, in each case, of *v* (valve), *p* (piston, or plunger), and *cyl.* (cylinder), the action of the pump may be understood

the cylinder to pass through the piston into the space above it. When the piston reaches the bottom of the cylinder, the water in the cylinder will be above the piston. As the piston ascends, the water in the cylinder, which is now above the piston, will be lifted by the piston and may flow out of the spout. When the piston ascends, lifting above it the water in the cylinder, it does not leave the lower part of the cylinder empty. The water

in the well flows up the pipe into the cylinder and fills it to the bottom of the piston. Since the piston is above this water, it cannot be said that it lifts the water, for it does not in any way have a hold on the water below it, yet the water rises.

167. Why the water rises in the pump. The rise of the water in the pipe of the pump is due to atmospheric pressure. The atmosphere is pressing downward upon the surface of the water in the well with a force of approximately 15 pounds to the square inch. This pressure is transmitted to the water within the pipe as an upward force. If the pipe were open at the top, the atmosphere would exert the same pressure of 15 pounds per square inch upon the surface of the water within the pipe, and the two forces would counterbalance one another. In that case the water in the pipe would remain at the level of the water in the well. Since the pipe is tightly closed by the piston which supports the pressure of the atmosphere, there is no downward pressure exerted upon the water below the piston, but there is an upward force of 15 pounds to the square inch transmitted to it by the water in the well. The atmospheric pressure will force the water up the pipe and against the piston. If the pipe is too long, the water may not reach the cylinder; it will stand at such a height that the downward pressure in the pipe, due to the weight of the water, will be equal to the atmospheric pressure outside. Since, as noted above, the height to which the atmospheric pressure will raise a column of water is about 33 feet, the so-called suction pipe should not exceed this length.

If it is desired to raise water to a greater height than 33 feet, the cylinder must be kept near the water in the well. Usually the cylinder is placed low enough to be always under water if the water is to be lifted to any great height.

168. City and district water supplies. The "old oaken bucket" and the town pump have been celebrated in literature, but they are not satisfactory as sources of water in modern cities. It would be extremely difficult to secure from wells a supply sufficient for a large city, and, furthermore, the soil in cities becomes so filled with various waste materials that the water from

ordinary wells is not suitable for use. Moreover, the desire for modern conveniences and sanitary appliances, such as bathtubs and toilet facilities, requires such large amounts of water conveniently available that carrying water for a household from a well is no longer practicable. For these reasons all cities in our

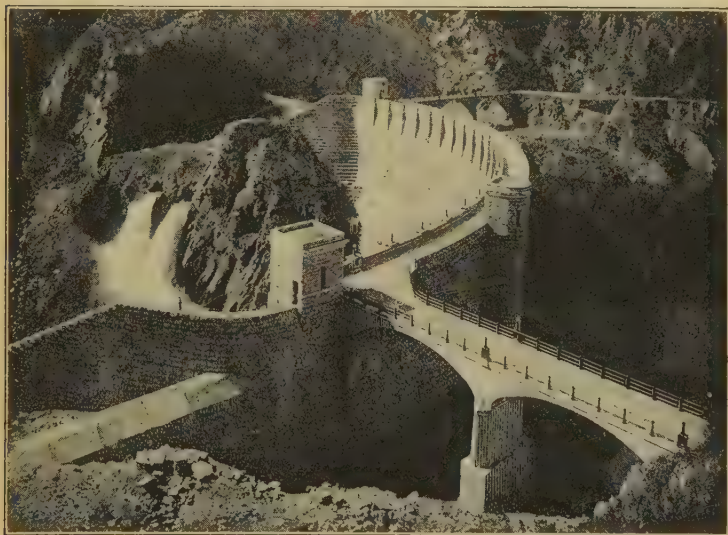


FIG. 80. A modern device for providing water

The Roosevelt dam on Salt River in Arizona is 280 feet high and 1080 feet long. The water which it holds back forms an artificial lake with an area of 25.5 square miles. The impounded water is expected to meet the needs of people who are scattered over 190,000 acres of land. Photograph by the United States Reclamation Service

country and many of the smaller towns and villages and sometimes large districts under government management have provided public water supplies (fig. 80). The water is conducted to houses under pressure in pipes, the pressure being furnished by a central pumping station or by gravity.

Community water systems of this sort have been in use only a little over a century, though other types of public works for

this purpose were in use even among ancient peoples. The first really satisfactory modern system was begun in Philadelphia in 1804. Previously the inhabitants of cities had been compelled to rely upon wells for their water, with consequent unsanitary conditions due to both the limited amount used for cleansing-purposes and the unsuitability of the water for drinking. It is estimated that when water is not piped to the houses, not more than four gallons per person per day will be used; but when water under pressure is available in a city, provision must be made to supply at least fifteen gallons per capita daily. This amount is greatly increased by manufacturing plants. The free use of water is a great aid to cleanliness. This abundant supply can be secured only through a system of public financing and management. How much water is supplied in your community? From what source, by what means, and at what yearly cost?

169. The need for a reserve supply. It is necessary that the water in the pipes be kept under pressure, in order that it may flow from the faucets freely at all times. Even in the houses that are in the highest parts of the town, the pressure must be sufficient to make it available for fighting fires as well as for household uses. Some towns are so located that it is possible to secure water from a source high up in hills close by, whence it flows by gravity through the pipes. If the source is considerably higher than the highest parts of the town, the pressure will be sufficient for all purposes.

Most towns and cities, however, are so situated that water must be kept under pressure by the aid of pumps, and for this purpose large pumping stations are established. Often an elevated tank, reservoir, or standpipe is connected with the system. If water is pumped faster than it is used, the excess backs up into this reservoir, and the pressure is determined by the height of the water in the reservoir. If water is used faster than it is pumped or if the pumps are stopped, the reservoir will continue to supply water for some time. Many of the new water plants are not supplied with reservoirs, and the pressure is controlled by regulating the speed, number, or size of the pumps.

170. Small-unit system. The convenience and sanitary advantages of having water piped to the house have been enjoyed only by those living in towns. It is possible to secure the same advantages in the country. The water may be pumped by a windmill, a gasoline engine, or an electric motor. It is stored in a tank sufficiently elevated to afford satisfactory pressure, or an air-pressure tank is used (fig. 81).

The air-pressure tank, commonly called a pneumatic tank, is now commonly used on account of its many advantages. It is a closed cylindrical steel tank, the lower part of which is filled with water, while the upper part is occupied by air. The air is compressed as the water is pumped into the tank. When the tank contains sufficient water, the pump may be stopped, and the pressure will be maintained by the compressed air in the tank so that water may be drawn from the faucets at any time. Provision must be made for pumping additional air into the tank from time to time. The pneumatic tank does not require unsightly or expensive construction to support it as does the overhead tank.

It may be placed in a corner of the basement, where it is safe from frost and at the same time conveniently located for inspection and repair. With proper water supply provided, most of the sanitary advantages of the city dwelling are equally available in the country.

171. Proper handling of water in the house. In modern well-built houses much attention is given to proper plumbing to insure the delivery of water to the parts of the house where it is needed and to avoid contamination. Small pipes are attached

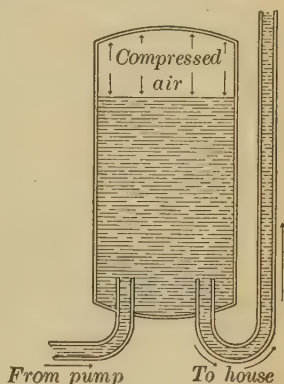


FIG. 81. Compression tank for rural water supply

Water may be held in the tank under pressure of the air by means of a valve in the pipe from the pump, and when the house faucets are opened, the compressed air forces water through the faucets

to the large pipes or mains underground in the street. The small pipe enters the basement of the house, and branches then

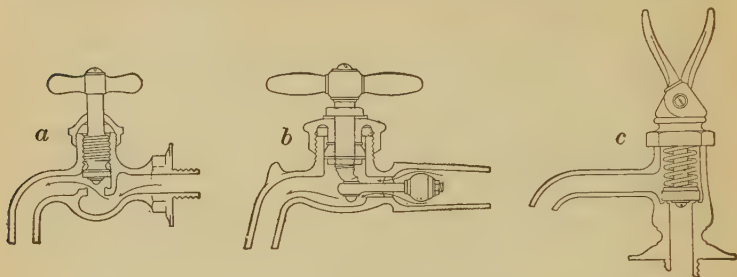


FIG. 82. Types of water faucets

The faucet *a* must be closed by hand; *b* is self-closing by water pressure; *c* is self-closing by pressure of a wire spring

lead to the parts of the house where water is needed. Owing to the high pressure produced in the mains by means of the pump-

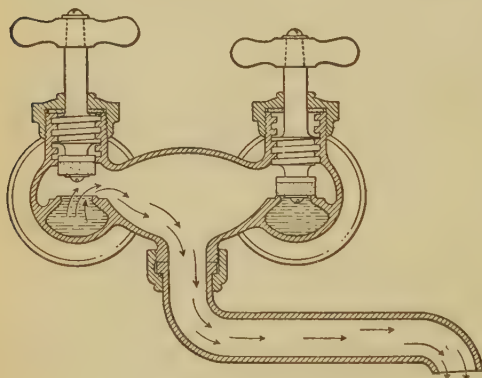


FIG. 83. A two-way faucet

A pupil's design for a faucet which permits mixing hot and cold water. The right-hand faucet is closed; the left-hand faucet is open

ing station or the height of the reservoir, the water may be drawn off at the faucets. The ordinary user of water has little to do with the system except to use the faucets and to pay the bills for service. Several types of faucets (figs. 82 and 83) are commonly used. Whenever a larger quantity of water is needed in a short

time, as for flushing a water closet, a tank is used in such a way as to be filled through a faucet which is opened and

closed automatically by a floating hollow ball or by a siphon valve. The tank (fig. 84) is emptied by pulling a chain or pressing a lever which opens the tank directly or starts the siphon. When the tank is empty, the water flows in at the faucet until the hollow ball has risen to a point where the metal arm to which the ball is attached has closed the faucet.

The waste water from the house is collected through sinks, wash basins, bathtubs, laundry tubs, water closets, refrigerator drains, and the overflow from tubs, basins, etc. Each of these fixtures (fig. 85) is connected with the drain pipes which carry

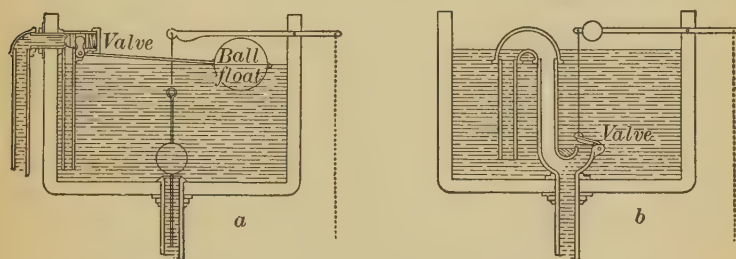


FIG. 84. Types of flush tanks

In *a* the valve for the entrance of the water is closed when the water in the tank has floated the ball to the level shown. The outlet pipe at the bottom is closed by a sphere of metal. In the tank *b* the entrance pipe is not shown. The outlet pipe is opened by a ball valve in *a* and by a hinge valve in *b*

the house wastes into the sewer. These connections should always be made by means of a trap, to prevent gases and odors from entering the house. Various kinds of traps are used, but in each some water is caused to remain in the trap in such a way as to seal the opening. This prevents the passage of air currents which might be objectionable.

172. Water pressure. Questions may arise as to the height of water in a standpipe or the elevation of a mountain spring which would be necessary to provide a given pressure. In order to gain an understanding of such problems, it is necessary to learn the natural laws which govern the pressure exerted by a body of water.

Let us set ourselves the problem of discovering the pressure upon the bottom of a rectangular aquarium tank the bottom of which is 6 inches wide and 24 inches long, and which is filled with water to a depth of 1 foot. The bottom will be

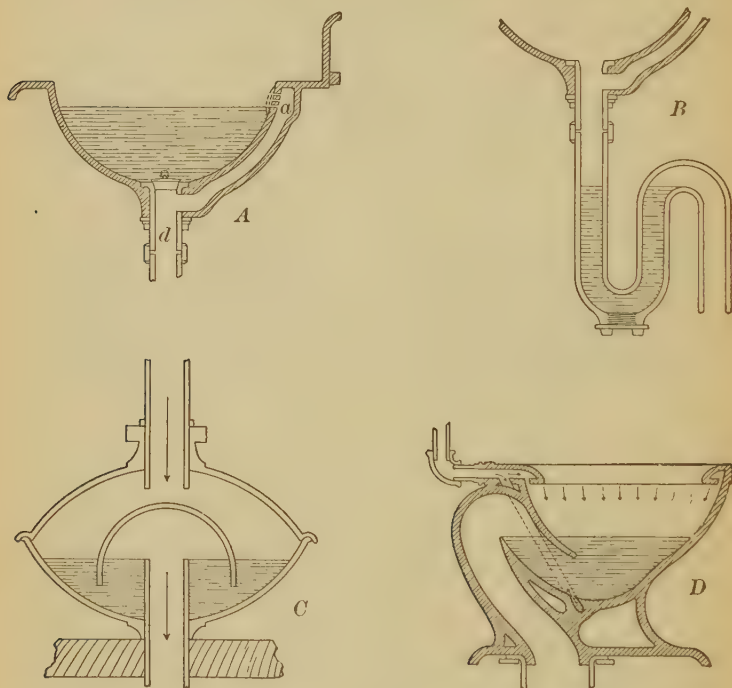


FIG. 85. Types of water basins and traps

A, wash basin with safety overflow devices: excess water flows through *a* and out at *d*; *B*, trap below wash basin; *C*, trap below an ice refrigerator; *D*, overflow pipe constructed with entrance pipe

pressed upon by the weight of the water in the tank, and the total pressure on the bottom will be equal to the weight of the water. If the bottom is 6 by 24 inches, its area is 144 square inches, or 1 square foot, and the total amount of water in the tank is 1 cubic foot. The pressure on the bottom is therefore

the weight of 1 cubic foot of water, and this is 62.5 pounds. The pressure on each one of the 144 square inches of the bottom is equal to 62.5 divided by 144, or 0.434 pound. Therefore the bottom of the box is under a pressure of 0.434 pound per square inch.

The cubic foot of water may be thought of as being divided into vertical columns 1 inch square, in which case there would be 144 such columns, one above each square inch of the bottom. Each square inch of the bottom may be thought of as supporting the weight of one of these columns, each of which contains 12 cubic inches. A cubic inch of water will weigh 62.5 divided by 1728, which equals 0.0362 pound, and the entire column of 12 cubic inches will weigh 12×0.0362 pound, which is exactly 0.434 pound, as in the former calculation. If the depth were not 12 inches, but only 6, the pressure would of course be only one half as great (6×0.0362); if it were only 1 inch deep, it would be 0.0362 (that is, 1×0.0362 pound per square inch). It follows that the pressure at any point beneath the surface of the water in an open vessel depends upon the depth at that point.

173. Actual pressures in a city system. In a city water system with an elevated reservoir, the pressure at any faucet will depend in the first place upon how far the faucet is below the level of the water in the reservoir. Thus, if the faucet is 100 feet lower, the pressure will be $.434 \times 100$, or 43.4 pounds, with the faucet closed. If there is no standpipe or other reservoir, the pressure will of course depend upon the action of the pumps.

If the faucet is open, effective pressure at the faucet is decreased somewhat by friction as the water flows through the pipes. If the pipes are sufficiently large, the effect of friction is not important; but if they are too small, or if they have been partly closed by sediment, the pressure may be greatly reduced.

174. The force pump. Pumps used for lifting water to a point some distance above the pump or for maintaining pressure in city mains must differ in two particulars from a common lift pump. The piston and valves may remain the same, but in

order that the water may not escape around the pump rod, it must be packed water-tight. In order to secure ease of working and steadiness of flow, an air chamber is provided. During the upstroke of the piston, part of the water passes into the air chamber, compressing the air; during the downstroke the air expands and forces this water out through the delivery pipe.

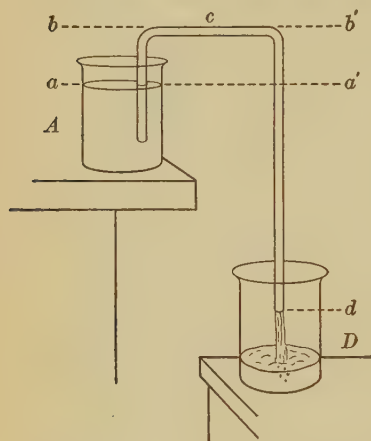


FIG. 86. The siphon

Water flows from *A* into *D* when *d* is below the line *aa'*, if the tube is first filled with water. The water is lifted to the level *bb'* by atmospheric pressure

175. Water and the siphon.

The siphon may be used to transfer water or any other liquid from one vessel to another over an elevation. This can be done only in case the outlet of the siphon is at a lower level than the surface of the liquid which is being transferred. For instance, in the illustration (fig. 86) the tube, which serves as a siphon, is represented as transferring water from the beaker at *A* to the one at *D*, which is at a lower level. In starting a siphon to work it is necessary to fill the tube with the liquid.

The liquid will flow through

the tube if there is a greater force acting in one direction than in the other. In the experiment shown in the illustration the upward pressure in the short arm of the tube is due to the pressure of the air. In the tube at *b* this pressure is equal to the atmospheric pressure minus the downward pressure which is due to the weight of the column of liquid *ab*. The upward pressure in the tube at *b* is the atmospheric pressure minus the downward pressure due to the column *b'd*. The force tending to drive the liquid from *A* to *D* will therefore be greater than that tending to drive it in the opposite direction. It will be greater

by an amount equal to the difference in weight of the two columns of liquid, corresponding to the height $a'd$. Evidently the siphon will cease to operate if d is at the level of aa' or if the distance ab is greater than the distance the liquid will be raised by the atmospheric pressure. This is about thirty-three feet in the case of water and about thirty inches in the case of mercury.

176. Dams. The building of dams in order to confine water or raise the surface to a higher level is very common (fig. 87). They need to be constructed with a great deal of care in order to be able to withstand the weight of water to which they are subjected. The pressure to which a dam will be subjected depends upon the depth of the water and the area of the submerged part of the dam. A great many lives and much property have been lost by reason of the floods which have been released by the breaking of dams. One of the greatest catastrophes of this kind was the breaking of the dam near Johnstown, Pennsylvania, in 1889. About two thousand lives were lost in the flood which resulted.

The pressure of the air, like that of water, is due to its weight, but we cannot measure the depth of the air and calculate its pressure as we do with water. We therefore rely upon the barometer, which is, in fact, a pressure gauge, to give us our information about air pressures (Chapter II).

177. Buoyancy. It is a familiar fact that objects appear to be lighter in the water than out of it and that some things float on water. No one has failed to notice this effect when bathing. The floating effect of water may be determined by weighing objects while suspended in the air and again while suspended in water. If we take a cubic centimeter of each of several different kinds of substances that are heavy enough to sink in water, and weigh each in this way, we shall find that each appears to lose one gram of its weight when put into water. No matter what differences there may be in the substances, if the pieces are of the same volume they will be buoyed up by the same force. The objects are buoyed up by a force (1 gram)



FIG. 87. A large dam

This dam was built by the United States Reclamation Service to store water for irrigation. It is 328 feet high and is said to be the highest structure of the kind in the world. Photograph by the United States Reclamation Service

which is precisely equal to the weight of the volume of water they displace when immersed (1 cubic centimeter). It is found that all objects which are immersed in water are buoyed up by a force equal to the weight of the water they displace.

In order to assist in explaining why objects are buoyed up by the water, let us imagine a cube measuring 1 centimeter on each edge submerged beneath the water so that the top is 10 centimeters from the surface (fig. 88). The pressure on each of the four sides will be 10.5 grams, since the average depth of a side is 10.5 centimeters. The pressures on the sides exactly counterbalance each other, and the object is not moved either to right or to left. The pressure is 10 grams on the top and 11 grams on the bottom. (Why?) These two do not balance each other. The pressure upward is greater by 1 gram than the pressure downward. Plainly, such an object as we have supposed, if its own weight amounted to nothing, would be pushed up to the surface. If it weighed more than a gram, its weight would overcome the upward push and it would descend to the bottom.

178. Floating objects. If an object weighs less than the water it displaces, it will float or, if submerged, will rise to the surface. It will not rest with its top even with the surface of the water, but it will project far enough above the surface so that the submerged part will displace an amount of water the weight of which is equal to its own weight (fig. 89). For example, if the one-centimeter cube weighed 0.5 gram, it would rise until only half of it was under water, and it would therefore displace 0.5 gram of water. An iron pail will float on the water because,

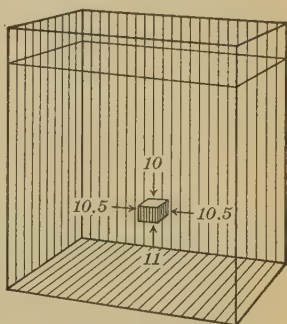


FIG. 88. Buoyancy

If a cube measuring 1 centimeter on each edge is submerged with the top 10 centimeters below the surface of the water, the pressures against the surfaces, in grams, will be as shown in the figure. Note that the pressure against the bottom is greater by 1 gram than that upon the top

though it is made of very heavy material, it is so shaped that it displaces a great deal of water. The iron ship floats for the same reason. The vessel therefore sinks in the water only deep enough to displace an amount of water equivalent to its own weight plus the weight of its cargo.

179. Submarines and balloons. A submarine boat is so constructed that no water can enter it, even if it is wholly submerged, excepting at the will of the occupants. If the occupants wish the boat to dive, water is admitted into special compartments in the interior until the weight of the boat equals or slightly exceeds the weight of the water it displaces. When

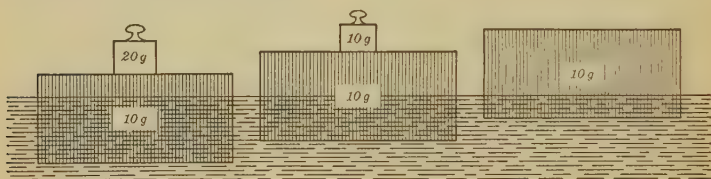


FIG. 89. Floating objects

The object at the right weighs 10 grams and displaces 10 grams of water. When a weight of 10 grams is placed upon it, as in the middle, it displaces twice as much water as at first. When the total weight is 30 grams, as at the left, the displacement is three times as great as at first

they wish to rise to the surface again some of the water is forced out. If the weight of the boat is kept very close to the weight of the water which it displaces, it is possible to steer it to right or left, up or down. The depth to which a submarine may safely descend is limited by the ability of the boat's hull to resist the pressure of the water.

A balloon operates on a similar principle. The bag is filled with a gas that is lighter than the air at the surface of the earth. The air buoys up an object with a force equal to the weight of the air displaced, and the balloon, being lighter than an equal volume of air, ascends. It will not rise to the top of the air, for the air is less dense at higher altitudes. It rises until it reaches a layer in the air of such density that the displaced air

equals the weight of the gas, balloon, and passengers, and it remains at that elevation unless something disturbs it. To reach a greater height, ballast may be thrown out, and it is possible to descend by allowing the gas to escape. The dirigible balloon may be steered upward and downward in the air, as a submarine may be guided in the water. As the density of the

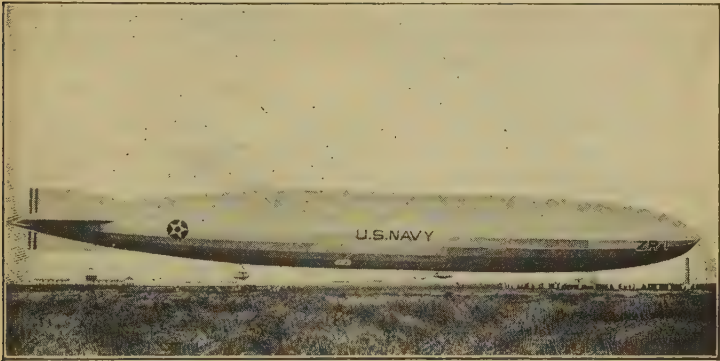


FIG. 90. Floating in the air

The United States Navy airship, the *Shenandoah*. This dirigible airship is 680 feet long, 79 feet high, has 20 gas cells with a total capacity of 2,115,000 cubic feet of gas, and has a total lifting power of 120,000 pounds. It has six 300-horse-power engines which combined can drive the airship at a speed of 75 or more miles an hour. The airship can cruise over a range of 4000 miles.

Helium gas is used in this and other modern airships

air varies at different levels, there are limits to the control of the balloon by use of rudders and ballast. Ballast, if dropped, might later be needed again.

180. Densities. In the preceding paragraphs attention has been called to the fact that an object in the water is buoyed up by a force equal to the weight of the water it displaces. Use may be made of this fact in several ways. We are enabled to determine the volume of irregular objects by this means, for it is evident that if an object loses 5 grams of weight when immersed in water, it must displace 5 grams of water. But water weighs 1 gram per cubic centimeter, and it therefore takes

5 cubic centimeters of water to weigh 5 grams. The object must have a volume of 5 cubic centimeters in order to displace 5 cubic centimeters of water.

The facts regarding buoyancy are useful also in enabling us to find the densities of different substances. By density is meant the weight of a unit volume of a substance—one cubic inch or one cubic centimeter. We might secure the weight of one cubic centimeter of iron by cutting a cube of that size and weighing it, but this would be a difficult process. Instead, we can take any irregular piece of iron, weigh it in the air and again in water, and from the weights calculate its density. The loss of weight in water is equal to the number of grams of water displaced and is therefore equal to the volume. The weight in air divided by the volume equals the weight per cubic centimeter, or the density. The density in ounces per cubic inch can also be secured, but the process is less convenient for use, and the density in grams per cubic centimeter is practically always used.

In the case of liquids the density is usually ascertained by weighing a measured quantity of the liquid.

Below are given a few common substances with their densities.

TABLE OF DENSITIES FOR REFERENCE

(Grams per cubic centimeter)

Alcohol . . .	0.8	Glass . . .	3.4	Olive oil . . .	0.9
Aluminum . .	2.7	Gold . . .	19.4	Pine wood . .	0.6
Brass . . .	8.4	Ice . . .	0.9	Platinum . .	21.7
Coal . . .	1.8	Iron . . .	7.2	Sea water . .	1.03
Copper . . .	8.8	Kerosene . .	0.8	Silver . . .	10.5
Cork . . .	0.2	Lead . . .	11.4	Tin . . .	7.3
Ebony . . .	1.2	Mercury . .	13.6	Water . . .	1.0
Gasoline . . .	0.6	Oak wood . .	0.8	Zinc . . .	7.1

CHAPTER XIII

SANITATION OF WATER SUPPLIES

181. Questions for discussion. 1. What are the principal sources of pollution of the streams in your community? 2. Is pollution of streams caused by necessity or carelessness? 3. Why is the water of a mountain lake commonly supposed to be free from disease-producing bacteria? 4. Is such water always safe? 5. What advantages come to a city as a whole from providing good water and from proper disposition of sewage?

6. When a sewer system has been provided, and certain house owners fail to connect their premises with it, is this a matter of any concern to their neighbors? 7. Is it a matter of concern to other citizens who live in distant parts of the city? 8. If waste matter is not properly disposed of on farm premises, may this concern residents of the neighborhood and of cities and towns close by? 9. What is the proper construction of a septic tank system of sewage disposal for rural use?

10. Can you locate records of a case where typhoid fever has been spread by the use of impure water or milk? 11. What was the evidence that water or milk was the source of infection? 12. What was done to prevent further spread of the disease? 13. What is the explanation of the fact that over 70 per cent of farm wells in Illinois less than 25 feet deep were found to be impure, while of farm wells 50 to 100 feet deep somewhat over 10 per cent were impure? 14. Secure from your state health department any available information regarding efforts to insure pure water for the state and make a list of the things which still need to be done.

182. Importance of pure water. The importance of pure water lies very largely in its relation to disease. We have learned that many kinds of bacteria are commonly found in water, and that no water is entirely free from them unless it has been sterilized. If these bacteria are of the kinds that produce disease, serious results may follow when the water is used for drinking and for domestic purposes.

The most important disease bacterium found in water is the typhoid bacillus (Chapter VII). For that reason the death rate from typhoid fever is often taken as a sort of index to the condition of the water supply. There is given here a graphic representation of the typhoid death rates in a number of cities (fig. 91). You will be able to draw your own conclusions as to the safety of the different sources of water supply.

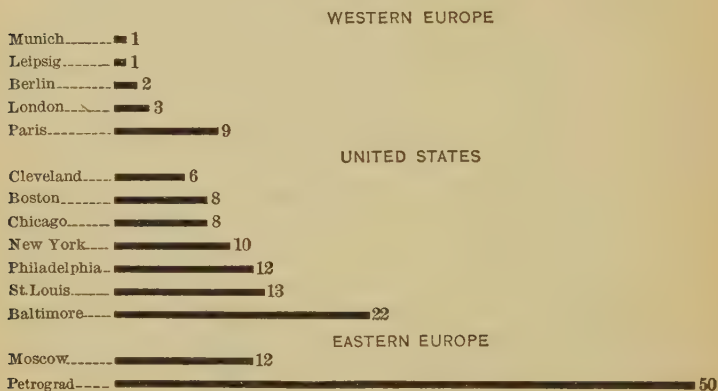


FIG. 91. Death rates from typhoid

The figures show the number of deaths per 100,000 population based upon data for 1912. The dark line indicates the proportionate number of deaths in each city. Get recent records for your own city and compare with the data here given

At one time Chicago had a typhoid death rate of 173 per 100,000 population, and at that time this was the highest recorded death rate from typhoid in the civilized world. The rate was only 13.7 per 100,000 in 1910, 7.6 in 1912, 5.1 in 1916, and 1.1 in 1922. The changes in water supply and sewage disposal, together with other modern methods of health control, have been important factors in securing this reduction.

183. Impurities in water. Some of the many kinds of impurities found in water are highly objectionable, while others are of very little consequence. These substances may be grouped in three classes: dissolved substances, sediments, and bacteria.

Certain dissolved substances in water produce what is commonly known as hard water. Hard water is an annoyance in many ways, but it is not known to have any serious effect on health. The chief annoyance is the curd that forms in it when soap is used, and it is also wasteful of soap. Lime, one of the most common substances dissolved in water, is deposited in a teakettle when hard water is boiled in it, and in this way the water is made soft. Some other substances in hard water cause more serious annoyance because they can be removed only by the addition of chemicals. Borax, sal soda, ammonia, and lye are commonly used for this purpose in order to save soap.

Sediments, or solid particles, of various kinds are present in all natural waters. We usually speak of them as mud, clay, sand, etc. If the water is allowed to stand for some time the sediment tends to settle to the bottom; but in rivers they remain in suspension for a longer time. The sediments present along the shore in lake waters have been brought in by rivers or stirred up by waves, there being little sediment in the water a few miles from land. Sediments make the water less inviting, but may not in themselves be dangerous.

The third kind of material—bacteria—is in reality a sort of sediment, but bacteria are of such importance that they will be discussed separately. Indeed, the principal importance of other sediments lies in the fact that bacteria are likely to be associated with them. The mud along the shore usually has a great deal of refuse mixed with it. There are great numbers of bacteria living in this mud, and if it is stirred up by the waves and mixed with water, the bacteria are likely to be distributed as widely as the mud is. Water which is muddy is often dangerous and always open to suspicion.

184. Sources of bacteria in lakes and rivers. Natural waters are never wholly free from bacteria. Every rain washes them into the streams. The most important source of bacteria in many of our streams is the sewage of the cities on their banks. The bacteria from this source are particularly objectionable because the sewage includes human wastes and therefore com-

monly contains the germs of such infectious diseases as are present in the community. As the water flows down the river many of the bacteria settle to the bottom along with other sediments or are killed by exposure to air and sunlight. Excepting near the source, very few rivers in their natural condition are suitable for domestic use.

The larger lakes are fed by many rivers and therefore receive large numbers of bacteria from them. Contamination is increased by refuse dumped alongshore and by the sewage of adjoining cities. The principal sources of contamination of lake waters are located near shore. The waters of the center of the lakes are polluted only as bacteria and other sediments are carried out into the lake by currents. The movements of lake water are so slow that bacteria and other sediments usually settle to the bottom before they have traveled many miles from land. For this reason the water in the central part of large lakes is usually of excellent quality. As cities increase in size, however, the zone of pollution alongshore extends farther into the lake.

185. Methods of securing pure water. The cities on large lakes have ordinarily taken their water supplies from the lakes. They have sought to secure pure water by constructing tunnels in the lake bottoms which make it possible to secure water from points at a distance of from one to six miles from shore. Even this distance is not great enough to guarantee pure water in all cases, and filtering or other means of purification is desirable.

Some cities are able to secure water from mountain streams which flow from valleys that are almost or quite uninhabited. The water of such streams is usually of excellent quality and, if protected from contamination by the inhabitants, will carry almost no disease-producing bacteria. Since the lands in the mountain regions are commonly of comparatively little value for agricultural purposes, it has been possible for certain American cities to acquire control of the entire drainage areas of the streams which supply them with water (fig. 92). With proper care these regions may be preserved from contamination, and

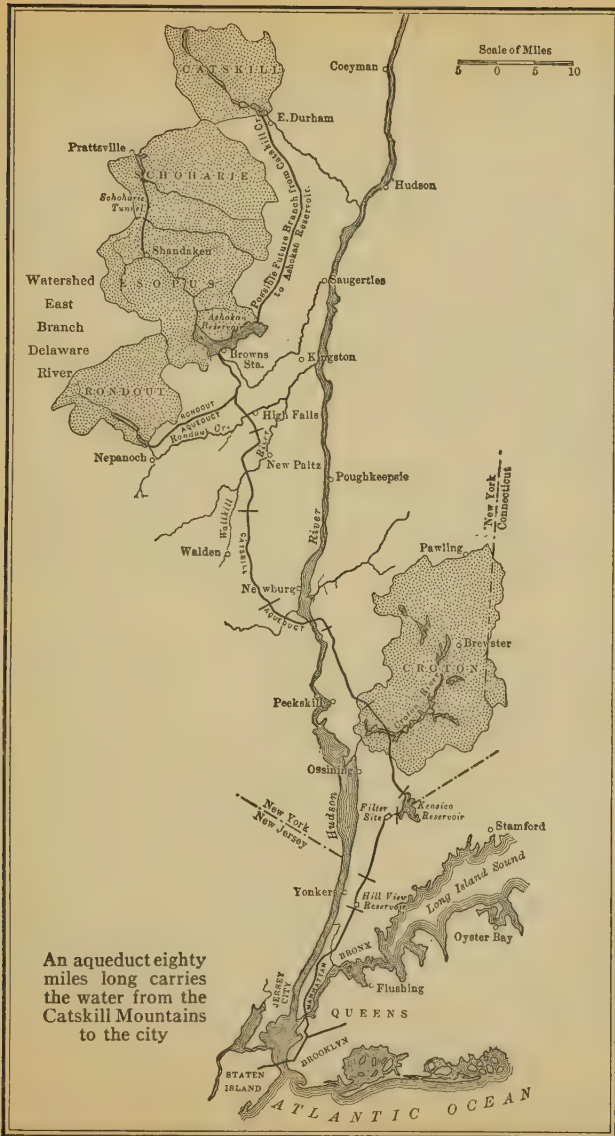


FIG. 92. The water supply of New York City

the purity of the water insured. The United States Forest Service is coöperating with certain cities in preserving from contamination those parts of the reserves which drain into the streams from which these cities derive their water supply.

For many cities the only available source of water supply is a river or lake which has become contaminated. In some cases this water is pumped into the mains without any attempt to avoid contamination. The result is that the health of the people suffers, and the death rate is abnormally high. The citizen of

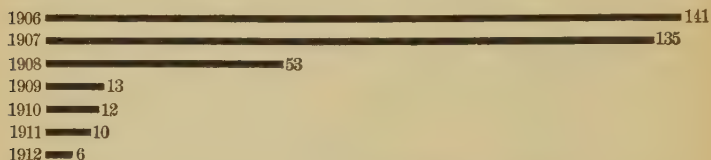


FIG. 93. Effect of purifying the water supply

Diagram showing the typhoid death rate per hundred thousand population in Pittsburgh, Pennsylvania, during a term of years preceding and a term following the installation of a filtration plant in 1908

such a city can protect himself from the danger of polluted water only by boiling the supply that he uses for drinking and domestic purposes.

186. Filter beds and reservoirs. All cities that are properly organized and governed guard the health of their citizens by careful attention to the quality of their water supply. If this must be taken from a contaminated source, it can be purified by any one of several methods. Many modern cities have installed filtering plants in which the bacteria are removed from the water by passing it through beds of sand (fig. 93). Other cities kill the bacteria by the action of certain chemicals which, when added to the water in proper proportions, are fatal to the bacteria but are not harmful to people.

Storage reservoirs in the form of natural or artificial lakes are common accessories of water systems. Usually the principal purpose of a reservoir is to accumulate a supply of water when it is plentiful, in order that there may be no scarcity dur-

ing a dry season or in case of unusual demands of any kind, as a great fire. At the same time the quiet waters (fig. 94) of the reservoir offer a favorable place for the finer sediments, including bacteria, to settle to the bottom. The water is thus purified to some extent while it is being held in storage, and in some water systems this is the most important means of purification used.

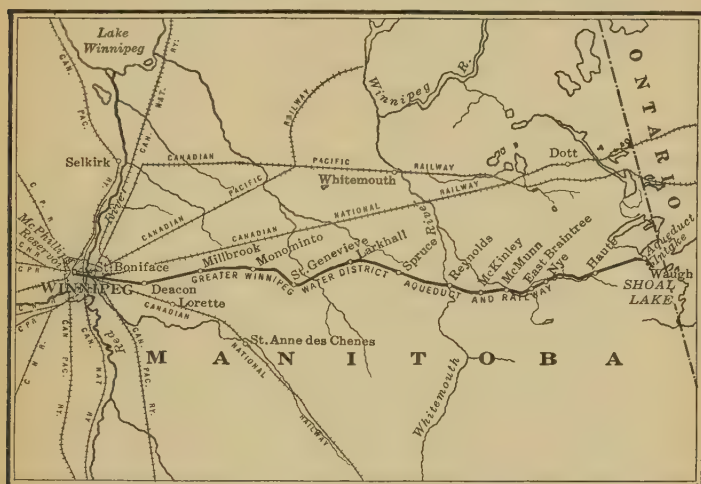


FIG. 94. The water supply of Winnipeg

Pure water from Shoal Lake, an arm of Lake of the Woods, is carried to the city through a concrete aqueduct more than ninety-six miles long

187. Sewage disposal. Much of a city's waste is in solid form (garbage, ashes, etc.), and the proper disposal of this is important and difficult. We shall here concern ourselves only with that which is washed away in running water—the sewage. That there will be a great volume of this is evident, for most of the water that is pumped into the city finds its way into the sewers. In addition most of the water from rains is turned into the sewers by the catch basins in the gutters.

The simplest way to get rid of waste water and sewage is to allow it to run off over the surface of the ground in gutters.

This objectionable practice is common in oriental cities, and even some American cities still permit such a system. Indeed, open sewers may be found in neglected parts of many of our cities. An open sewer is always a source of danger and should be a matter of concern to every citizen.

The modern and sanitary way to construct sewers is to place them underground. There is usually a sewer in every street, and every house should be connected with it. The smaller sewers unite with larger ones, which finally discharge the sewage into a lake, river, or ocean, or, what is far better, into a modern sewage-reducing plant.

188. A sanitary canal. As inland cities develop, their problem of disposal of sewage becomes more and more difficult. A type of the ways in which their problem is being met is taken from the largest inland city. Although Chicago is in the basin of the St. Lawrence River, at the present time its sewage flows into the Gulf of Mexico. The way this was accomplished forms an interesting illustration of what a modern city will do to dispose of its sewage so as not to spoil its water supply.

Most of the area on which the city is built is drained by the Chicago River, which formerly emptied into Lake Michigan. The sewers of the city naturally emptied into the river or into the lake, and thus the sewage was poured into Lake Michigan, which was also the only available source of water for the city. Not many miles west of the city flows the Des Plaines River, which is a part of the Mississippi system. The divide between the basin of the two great river systems—the St. Lawrence and the Mississippi—is here very low, being at one point not more than fifteen feet above Lake Michigan. This low and narrow divide afforded an easy passage for a canal built to carry away the sewage of Chicago.

This canal leads from the upper part of the Chicago River into the valley of the Des Plaines River. The current now flows from the lake into the mouth of the river and up the South Branch, where it enters a new canal, known as the sanitary or drainage canal, thus reversing the recent course of the river.

In this way part of the water of Lake Michigan, the normal outlet of which is through the St. Lawrence system, now flows into the Gulf of Mexico and carries with it the sewage of Chicago. In prehistoric times Lake Michigan stood at a higher level, and its waters emptied into the Mississippi system along the route now followed by the drainage canal.

The construction of the sanitary canal cost over \$56,000,000, and if it were built at the present time its cost would be two or three times that sum. The city health department reports that during the ten years before the opening of the canal, in 1900, the average annual death rate from typhoid fever was 66.8 per 100,000, but in the ten years following, the rate was only 22.3. It is calculated that this represents a saving of 8814 lives. Each life has a money value, dependent upon earning capacity. The health department has calculated that the actual money value alone of these lives to the community at the time the canal was built was nearly \$53,000,000. In other words, the canal almost paid for itself in the first ten years. It will pay any city to secure pure water at any necessary cost.

189. Sewage treatment. The common method of disposing of sewage and other wastes by discharging them into streams, lakes, or ocean is obviously highly objectionable, and the nuisance tends to increase with the growth of population. At many places it has become necessary to treat the sewage in a manner that will remove its objectionable qualities before allowing it to enter the watercourses. This is usually accomplished by bacterial action and filtration. Chemical treatment may be used, also, to destroy the bacteria. Sometimes the sewage is used to irrigate land.

190. Rural water supplies. The water supply of farms and villages usually does not receive so much attention as that of cities. Most of the inhabitants of a city secure their water from the public water supply, and any fault in the system affects the whole city, thereby attracting attention. In rural districts, on the contrary, each home has its own independent source of water, commonly a well, and contamination of any one well

does not affect so many people. It is quite possible, however, that many wells may be in a polluted condition at the same time, and the average character of the water in a rural community may be very bad. Indeed, typhoid and other water-borne diseases are often more prevalent in the country than in the city. City health officers have learned to expect an increase in the number of cases of typhoid in the city at the time of year when people return to the city from their vacations in the country.

The water in an ordinary well comes from the rain water which falls upon the ground within a few hundred feet of the

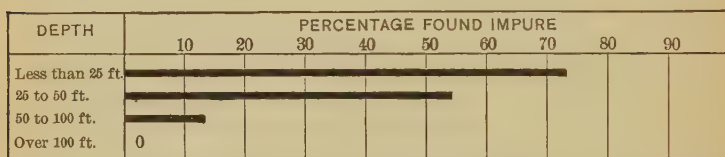


FIG. 95. Purity of farm wells

Results of the examination of farm wells in Illinois. Deep wells are more frequently pure. After data by Bartow

well and percolates through the soil until it reaches the well. Such water has usually been contaminated more or less at the surface of the earth with the various bacteria which may be present upon the surface or in the upper layers of soil (fig. 95). As the water percolates through the soil many of these bacteria are removed by the filtering action of the soil. If the bacteria are not too numerous, and if the soil is sufficiently compact and the distance the water travels through it is great enough, practically all the bacteria may be removed. On the other hand, if the well is located near a compost heap, cesspool, pigpen, or other source of pollution, it is almost certain that the water in the well will be contaminated. If the ground slopes toward the well, this will favor contamination. It is very desirable, therefore, that a well be located far from all possible sources of contamination, that the ground slope away from it in all directions, and that it be tightly curbed and covered.

In many communities water is secured from wells several hundred feet in depth. The water which enters a well from the deeper layers of the earth's crust has, of course, percolated a long distance through soil and rock and is very nearly free from bacteria, but such wells must be carefully guarded against the entrance of surface water. The lining of the well should be water-tight, and the surface waters carefully drained away from the vicinity of the well. A deep well protected so that surface water cannot enter is one of the most reliable sources of pure water.

191. Disposal of wastes in rural districts. In many rural districts the disposal of wastes is not given the attention that its importance demands. Too often manure heaps are allowed to become breeding places for flies, and human wastes accumulate in cesspools where they are accessible to flies and may become sources of contamination to wells. The barns and outbuildings often are in a condition that is a continual menace to health.

It is obviously impracticable to construct sewage-disposal works which will serve an entire rural district as a city is served by its sewer system. It is, however, entirely practicable for each country residence to have its own individual plant for this purpose as well as for the supply of water. The main waste pipe of the house should empty into a septic tank. This tank is so constructed that all sewage is inclosed and is not objectionable or injurious to people in the region. By action of bacteria the sewage is gradually reduced to a condition which is harmless and may be safely discharged into a stream or used upon the soil.

CHAPTER XIV

CLIMATIC INFLUENCES OF BODIES OF WATER

192. Questions for discussion. 1. Why does a deep river not freeze to the bottom of the water? 2. Why does sprinkling the streets lower the temperature of the air? 3. If a bathtub contains hot water, and an equal amount of cold water is turned into one end of the tub from the faucet, will the temperature of the water soon be the same in all parts of the tub?

4. Why is it possible to raise peaches in Michigan, while in Illinois the peach crop is very uncertain and the trees are sometimes killed by the cold? 5. Why do the ranchmen of northern Texas often lose stock from exposure to cold, although the general average of winter temperature is not low? Why would this loss be unlikely to occur if all winter winds were from the southeast? 6. What are some of the causes of the popularity of lakes and ocean shores as summer resorts?

7. How can you account for the fact that there are often breezes from water to land in daytime and in the opposite direction at night, although there may be no general wind disturbances over large areas at the time? 8. Why may one shore of a lake be much better for fruit-growing than another? 9. Why do the Bermuda Islands, in the latitude of Savannah, have a more uniform climate than Savannah?

193. Water and climate. Those who have gone bathing in river, lake, or ocean have noticed that the water is usually cooler than the surrounding air. The common practice of spending the summer season near lakes or ocean is not primarily for the sake of using the body of water, but because the surrounding air is likely to be cooler than the air many miles away from such bodies of water. The larger the body of water, the greater the influence on temperature. Since three fourths of the earth's surface is covered by water, it is clear that any effect water exerts on temperature is extensive. It is easier to see the nature

of this influence if we use as illustration bodies of inland water. The ocean has similar and even greater effects, but because of its size it is not so suitable for study.

After we have secured some definite information regarding the influence of a lake upon the surrounding territory, we should be able to apply this information to the explanation of

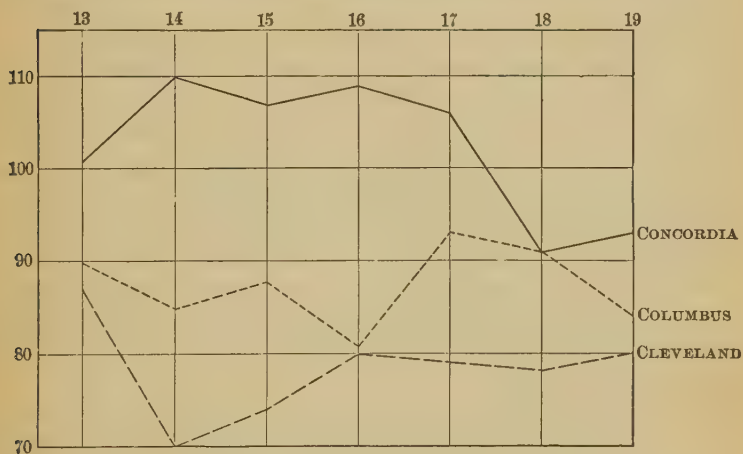


FIG. 96. Temperatures during a hot wave

The diagram shows the relative temperatures of Concordia (Kansas), Columbus (Ohio), and Cleveland (Ohio) from July 13 to July 19, 1913. Cleveland is on the shore of Lake Erie

the effect which bodies of water have upon the lives and industries of men in various parts of the world. For example, by studying figure 96 it will be seen that on July 14, 1913, Cleveland, Ohio, had a temperature of 70° F., while Concordia, Kansas, at a higher elevation, had a temperature of 110° F. The figure shows other interesting facts. During periods of warm weather the temperature at lakeside places is usually lower than at inland points in the surrounding country. On July 17, 1913, the United States Weather Bureau reported the highest temperatures for the day at Milwaukee, Chicago, Detroit, and Cleveland to be from 74° to 78° F., while at the same time the

adjacent parts of the Mississippi Valley were suffering from a hot wave and nine stations reported temperatures of 100° F. or higher. There were other days, however, on which the temperature of the cities named was as high as that of the neighboring places. In order to secure a clear idea of the conditions it is necessary to know the mean temperatures at the places compared.

194. Water and yearly temperatures. The accompanying table gives the mean monthly temperatures from many years' observations, as ascertained by the United States Weather Bureau, for three cities, two located on the shores of Lake Michigan and one in the adjacent country. The mean monthly temperatures are definitely lower during the summer months at the lake cities than at inland points in approximately the same latitude. There is foundation, therefore, for the belief that the shores of the lakes offer more comfortable summer temperatures than may be found at inland places. The same conclusions would be reached if other lake cities were compared with places remote from the lakes.

MEAN MONTHLY TEMPERATURES

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Madison . .	16.9	18.7	30.4	45.6	57.6	67.3	72.0	69.8	62.3	50.0	35.1	22.8	45.8
Milwaukee .	20.5	22.3	31.4	43.3	53.6	63.6	70.0	68.9	62.0	50.2	35.8	25.4	45.6
Grand Haven	24.6	23.8	31.5	43.8	54.4	64.1	68.8	67.3	61.2	50.1	37.9	29.2	46.4

195. Lake and sea breezes. Those who live near the shore of any large body of water are accustomed to attribute much of their freedom from great heat to the lake or sea breeze (fig. 97). This breeze frequently blows on hot days and gives relief from the heat. Often the morning is quite warm, with rapid increase of heat as the sun gets higher in the heavens, until about ten o'clock, when a cool breeze begins to blow from the lake and the temperature becomes comfortable again. The breeze may continue until about four o'clock in the afternoon or later. Its effect is most pronounced near the water, and it

does not extend many miles inland. The same phenomena are observed on ocean shores where they are usually more marked.

196. Cause of lake and sea breezes. To account for these breezes the causes for the movement of air need to be recalled (Chapter II). One cause is the difference in temperature. When air is expanded by heating, it becomes lighter; that is, a cubic foot of it weighs less, because the air that occupied a cubic foot of space before it was heated has expanded (Sect. 28). If next to the warm air there is a quantity of colder

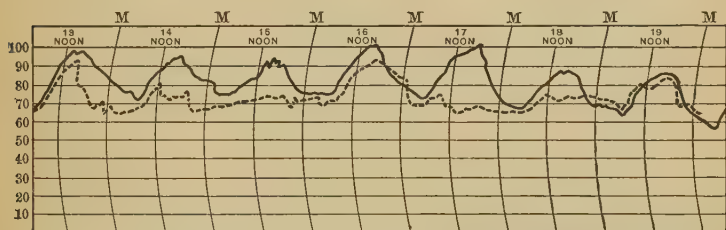


FIG. 97. Daily variations in temperature

Diagram showing the daily variations in two cities from July 13 to July 19, 1913. The solid line represents Peoria, and the broken line represents Chicago.

Note the effect of Lake Michigan

and heavier air, this colder air will tend to flow in under the warm air and lift it up. This is what happens in the vicinity of a stove or radiator, where the cool air is continually flowing toward the stove, where it is warmed and in turn displaced by the other cool air, thus making a continuous current.

The same thing occurs along a shore. In summer the land is much hotter than the water, at least while the sun is shining. Like the stove, the land heats the air which is over it until this air becomes so light that the heavier air above the water begins to flow out over the land, crowding the warm air upward (fig. 98). The air from the water becomes heated as it flows across the land, and rises as it is displaced by more air from the lake. Thus there is a continuous flow of air across the shore line from water to land as long as the land is hotter than

the water, excepting when local breezes are counteracted by stronger and more general movements of the air. The breeze gets well started about the middle of the forenoon, the time the land ordinarily becomes heated. During the night the land may be cooler than in the daytime; sometimes so much cooler than the water that the air flows from the land to the water, but this land breeze is much less noticeable than the lake breeze.

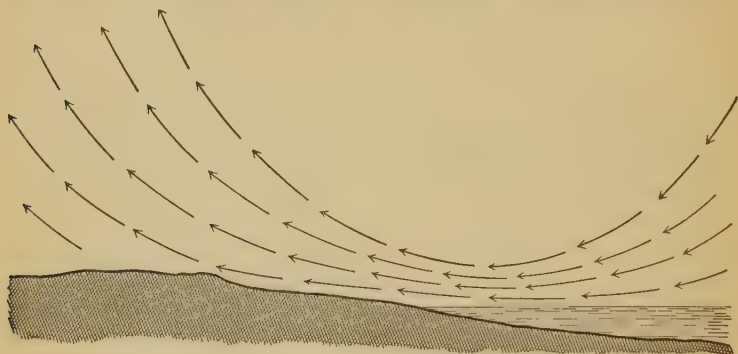


FIG. 98. Air movements from water to land

When the land is warmer than the water, cool and heavy air from the water flows over the land, pushing the lighter, warm air upward. Such movement of the air is known as a lake breeze or sea breeze

197. Causes of unequal heating of land and water. The more rapid heating of the land is due, first, to the fact that it is not transparent. All the heat of the sun is received on the surface of the land, and the upper few inches are very rapidly heated, while the lower parts receive the heat slowly. Indeed, so slowly is heat transmitted to the deeper layers of the soil that at the depth of a comparatively few feet the temperature does not change in either summer or winter. On the other hand, the sun's rays penetrate into the water to a considerable depth (fig. 99), the exact distance depending on the clearness of the water. If the water is clouded by sediment, the rays of the sun do not penetrate very far. A second reason is that since the sun's rays

are reflected from the water more than from the land, much of the heat is reflected also and does not actually enter the water. A third reason lies in the fact that the water moves easily. Waves and currents mix the warm surface waters with the cool deeper layers, thus scattering the heat widely. For these reasons, although a square foot of water will receive as much heat as a square foot of land, no part of the water is heated so highly.

The fourth and most important reason is found in the effect of a given amount of heat upon different substances. If a kettle of water and a flatiron are placed on a kitchen range at the same moment, the iron will be heated far more rapidly than will

the water. If a pound of iron and a pound of water are placed on the stove and exposed equally to the heating surface, it will be found after a short time that the iron is much hotter than the water. The same amount of heat has much less effect on the water than on the iron, so far as raising its temperature is concerned. The amount of heat which will warm a pound of iron 1°C . will warm a pound of water only 0.11 of 1°C .; that is, it takes over nine times as much heat to produce a given change of temperature in a given weight of water as in the same weight of iron. There are so many kinds of soil that if we were to use soil instead of iron for this experiment, the results would vary widely.

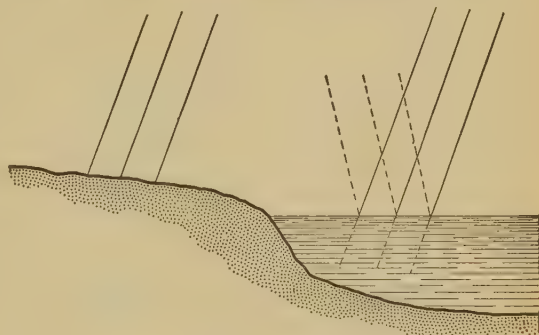


FIG. 99. Action of the sun's rays on land and water

When the sun's rays fall upon the surface of the land, they are mostly absorbed at the surface. The water reflects some of the light and heat, but the remainder may penetrate to considerable depths

198. Cooling of land and water. The land cools more rapidly than does the water. As it is necessary to put more heat into water than into land in order to raise its temperature a given amount, so the water gives off this larger amount of heat when it cools. Furthermore, as water cools it gives off its heat slowly, and since much of the heat is in the deeper parts of the water, it is not readily given off. We may therefore expect that any body of water will be cooler in summer than the neighboring land, at least during the daytime and while the sun is shining,



FIG. 100. Cities with different locations in the same latitude

and that breezes from water to land will be common. During the winter the water may remain much warmer than the land.

199. Extent of influence of water. Although the lake breezes are local, the temperature effect of the lakes is carried far inland by other means. It should prove instructive to compare temperatures throughout the year at localities on opposite sides of the lake, but near it, with one well removed from the lake but in the same latitude. Such localities are shown in figure 100. We need to study again the table of mean monthly temperatures (p. 174) in order to see what this effect is. Since the three points Grand Haven (Michigan), Milwaukee (Wisconsin), and Madison (Wisconsin) are in the same latitude (fig. 100) and so located that one is close to the east shore of the lake, one near the west shore, and one removed from the lake, we shall have proper points for comparison.

In the summer months we find that the means are a little lower at Grand Haven than at Milwaukee, and are highest of

all at Madison. In the case of these three towns, at least, it appears that the lake may bring about lower summer average temperatures in its vicinity, particularly on the eastern shore. We cannot be sure of a general law by studying three cities only, but from many such studies it can be stated that a similar condition is found to exist in all places in this region.

MINIMUM DAILY TEMPERATURE DURING A COLD
WAVE IN 1913

DATE	CHICAGO	DUBUQUE	GRAND HAVEN	GRAND RAPIDS	MADISON	MIL- WAUKEE	ST. LOUIS	SIoux City
Jan. 2	5	-5	9	9	-8	-4	16	-13
3	5	-6	9	9	-8	-4	9	-9
4	-6	-9	2	2	-12	-11	7	-13
5	-10	-19	-1	-2	-23	-18	-1	-20
6	-11	-19	0	-1	-24	-18	-9	-20
7	-16	-22	-3	-5	-24	-18	-14	-26
8	-3	-3	-2	-2	-7	-5	0	-7
9	-4	-10	3	2	-14	-10	10	-5
10	-6	-15	2	0	-15	-13	4	-7
11	-3	-19	-3	1	-19	-14	-2	-26
12	-3	-26	-14	-9	-25	-14	-9	-35
13	-1	-18	-2	-1	-20	-9	-8	-8
14	4	-2	10	9	-2	0	12	-9
15	-2	-10	5	3	-10	-5	-4	-17
16	-2	-12	5	2	-11	-5	0	1

If it is the winter temperatures to which we give our attention, we find that again the west shore occupies an intermediate position, the east shore is warmer, and the country away from the lake much cooler. In the table given above there is given the record of the lowest point reached by the thermometer on each of several days during a severe cold wave in the first part of January, 1913. The illustration (fig. 101) represents in diagrammatic form the conditions in three cities. It will be noticed that the cold is less severe on the east shore than on the west, and less severe on either shore than at places far distant from the lake but in the same latitude.

200. Causes of difference between east and west shores. It will be recalled that in connection with the study of the wind movements of the earth we found that the United States is in a belt of prevailing westerly winds. We have winds from all points of the compass, but our winds much more frequently

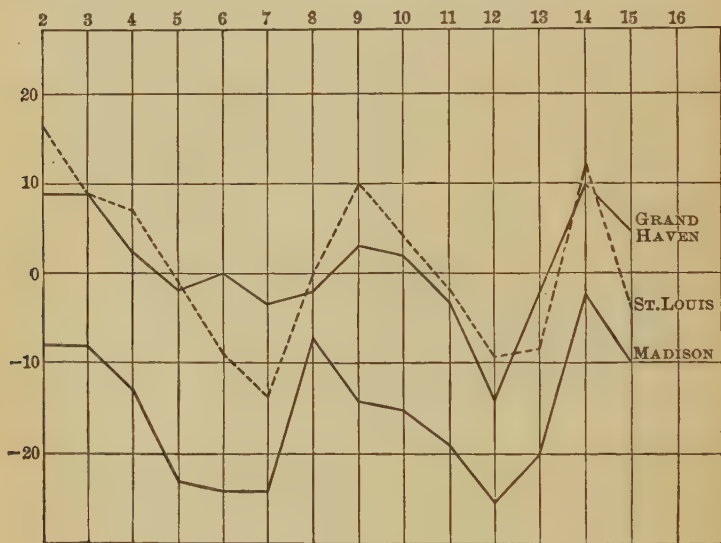


FIG. 101. Temperatures during a cold wave

The diagram represents the variation in temperatures between three cities on the dates January 2 to January 15, 1913. Grand Haven is in the latitude of Madison, but its temperature is like that of St. Louis

blow from a point west of a north-and-south line than from a point east of such a line. They are usually southwest, west, or northwest. It follows from this that on most days of the year the air over the country to the east of the lake has come across the lake. On the west side the influence of the lake is very slight excepting on a few days when the wind is from an easterly direction or when the west wind is so light that a lake breeze develops. The effect of the lake is particularly

important in case of a cold wave, for our coldest winds are from the northwest.

The influence of lakes tends to reduce the extremes of temperature. Places near lakes have on the average cooler summers and warmer winters than they would otherwise have. This



FIG. 102. Vineyards and bodies of water

Large bodies of water tend to delay spring development and thus to avoid injury from frosts. They also assist in providing a more even climate. About Lakes Erie and Ontario are thousands of acres of vineyards

effect is great enough to be of some importance on the west shores of the lakes, but it is of much greater importance on the east shores.

Similar conditions will be found in the vicinity of any large body of water in a temperate latitude. In tropical countries, where there is no cold season and the winds are easterly, condi-

tions are somewhat different, but the same principle applies. The western coast of each continent is warmer than the eastern coast in the same latitude.

201. Some effects of lake climate.¹ The coolness of the summer months attracts thousands of people from the hotter parts of the country to the shores of lakes and oceans. Thousands of summer residences have been built and whole summer cities have grown up along shores which are sometimes so barren that were it not for the favorable summer climate scarcely anyone would live there. During the winter these settlements are often almost wholly deserted.

Back from the shores of the Great Lakes and for many miles inland the climate is so modified that it is possible to grow fruits which cannot be grown with success away from these lakes, excepting some hundreds of miles farther south. For instance, peaches are grown on the east side of Lake Michigan, but they do not succeed well on the west side; indeed, it is necessary to go as far south as southern Illinois and middle Missouri to find an equally favorable climate. Similarly, grapes and other fruits are extensively grown near Lakes Erie and Huron.

The influence of the Lakes hinders the occurrence of early frosts in autumn and delays the return of warm weather in spring. Fruit trees and vines are thus prevented from starting growth during an occasional warm spell in spring and are often preserved from the dangers of late frosts. The mildness of the climate of the Pacific coast even as far north as Alaska is due to the influence of the ocean, assisted by certain ocean currents, and many other similar illustrations might be cited.

¹ In this chapter and the one that follows, conditions about the Great Lakes are frequently cited as illustrations. This is done because of the extensive development of the region and because it represents the most extensive inland navigation of the world. Conditions in other regions where the records have been kept for a considerable period will serve equally well, and such records should be secured as a means of demonstrating the local importance of the facts under discussion.

CHAPTER XV

WATER AND COMMERCE

202. Questions for discussion. 1. What large cities of the United States are located on large bodies of water and at the mouths of large streams? Why are they so located? 2. Why is it that early settlements in the United States began on or near bodies of water? 3. Who were the first settlers in your state, and by what routes did they enter it?

4. What are the leading ship canals of the United States? 5. In what ways has the transportation of your state been influenced by lakes, oceans, or rivers? 6. Is water transportation as important or more important in your state now than it was a century ago? 7. Are there towns or communities in your state wholly dependent upon water transportation? 8. What is the purpose of lighthouses? of life buoys? 9. Why does the United States government and not the state governments take charge of lighthouse stations?

10. Of what advantage or disadvantage would it be to Mississippi and Louisiana to have the Chicago Drainage Canal and the stream into which it empties made large enough and deep enough to permit large steamers to pass through them? 11. What advantages or disadvantages to the producing industries of the country might result from increased use of the Erie Canal from Buffalo to the Hudson River at Albany? 12. What advantages or disadvantages might result from opening the St. Lawrence River and the Great Lakes to ocean-going ships?

203. Use of waterways. In the autumn of 1922, when coal-mining had been resumed after a strike lasting all summer, there was great anxiety among the people of Minnesota, the Dakotas, and other northern and northwestern states as to how much coal from the East could be shipped to them before ice closed navigation on the Great Lakes. It was realized that the railroads would not be able to transport quickly the large amount of coal necessary, without the assistance of waterways.

The Great Lakes afford a waterway for large ships all the way from Pennsylvania to Minnesota. Thus people as far apart as those in eastern Pennsylvania and North Dakota or Montana were very directly interested in the navigation of the Great Lakes.

The inland waterways of North America as well as those of other countries are extensive and important (figs. 103 and 104).



FIG. 103. Use of waterways in Holland

Canals are important routes of travel for business or pleasure. They serve also to carry away surplus water pumped into them by the windmills

The traffic through the Sault Sainte Marie Canal, connecting Lakes Superior and Huron, is about four times as great as that through the Suez Canal, even though the Sault Canal is closed by ice about five months of the year. A yet greater amount of traffic passes through the Detroit River, and this is one of the busiest waterways in the world. It is said that during the World War an average of one ship every fifteen minutes passed the city of Detroit. Much of the commerce of Chicago, the greatest railroad center in the country, is carried by water.

204. Advantages of water transportation. One of the principal advantages of water transportation is that it is usually cheaper. It costs a great deal to build railways, while the principal waterways are provided by nature. However, it is expensive to provide and maintain harbors and docks. On the whole, the expense per ton for moving freight is usually less by water than by land.

Water transportation is usually slower than transportation by rail, hence the things shipped by water are usually such commodities as coal or lumber, the demand for which it is possible to estimate many months in advance. It is not always true, however, that the railways are more rapid. Sometimes they are so crowded that freight is not sent on promptly, and cars are allowed to stand on sidetracks for days. A ship, on the other hand, usually proceeds quite promptly from one port to another. It may move more slowly, but since it does not stop so long or so often it may arrive before the car does. Heavy and bulky articles, such as coal, iron ore, stone, lumber, and grain, are commonly transported by the water routes where this is possible. One of the most important phases of the use of the Lakes today is the transportation of iron from the mines near the west end of Lake Superior and near Green Bay to the private wharves of the steel plants. The ships are built for this service and carry no other freight unless it may be a return cargo of coal. Lines of boats run through Lakes Superior, Michigan, Huron, St. Clair, and Erie to Gary, Cleveland, Buffalo, and other ports, where the iron ore is smelted, or from which it is shipped to inland points. Other important articles of commerce which might be shipped on inland or coast waterways are coal, grain, and lumber. The Great Lakes and the St. Lawrence River have possibilities which as yet the United States and Canada have not fully used.

Many of the industries of the lake ports depend largely upon the materials which are brought by water, and many citizens are there because of the opportunities afforded them by the industries which depend wholly or in part upon this commerce. It

is true that these cities might be able to exist without the lakes, as other cities do; but they would doubtless be different in many respects, and it is quite possible that they might not have been established or that they might be at different places and engaged in different activities.

205. Origin of lake cities: Chicago as a type. The first white settlers and travelers in the region of the Great Lakes were the French. They came into the country by way of the St. Lawrence River and early discovered the Great Lakes. As they pushed their explorations farther west they adopted the Indian canoe as their chief means of travel, and the most important roads for them, as for the Indians, were the rivers and lakes (fig. 105).



FIG. 105. Early routes of travel

The map shows the headwaters of rivers and the lakes which were important in determining the courses taken by early hunters and settlers. Portages shown by ■■■

When they had discovered the Mississippi River and formed settlements and military posts upon it, their route from Canada to the Mississippi was through the Lakes to the shore of Lake Michigan, then up some stream emptying into the lake, and across the country to another river down which they might float to the Mississippi. There were several such routes in use. One of them crossed the present site of Chicago. When traveling by this route the *voyageur* paddled his canoe to a point near the south end of the lake, where he entered the Chicago River. He followed the south branch of this stream to a point near the western limits of the present city. A short carry, or portage,

brought him to the Des Plaines River. Indeed, in times of flood it was often possible to travel almost the entire distance by canoe. Once in the Des Plaines River, he might easily pass with the current down to the Illinois River, to the Mississippi, and even to the Gulf of Mexico. French posts on the Illinois River made this a favorite route. When sailing-ships began to be used on the Lakes, it was natural that the traveler should wish to go as far as possible on the ship and as short a distance as possible in the canoe. Ships brought travelers and goods to the south end of the lake, and the mouth of the river afforded a safe harbor for the vessels and a landing place for the goods. The French lost possession of the country, but the route of travel and commerce did not change.

When travel and commerce had increased, people began to settle at the point where the ships came to unload. A fort was built to protect the settlement and to defend the route of travel. This was known as Fort Dearborn, and its site is in the center of the present city of Chicago.

206. Extension and improvement of waterways. As population increased, the need for good transportation facilities increased also. Steamboats abounded on the larger rivers, and sailing-vessels on the Great Lakes, but there was no route by which freight vessels could pass between the Lakes and the greater river systems. To meet these needs a number of canals were dug. Erie Canal is the most widely known, but there are others in Pennsylvania, Maryland, New Jersey, Delaware, Ohio, Illinois, and other states (fig. 106).

One of the canals was completed in 1848 and connects Lake Michigan with the rivers of the Mississippi system. The conditions which made it easy for the French and Indians to get their canoes from Lake Michigan to the Illinois River by way of the Chicago and Des Plaines rivers also made it easy to dig a canal, known as the Illinois and Michigan Canal, along the same line. The divide between the two rivers is at one place not more than fifteen feet higher than the lake. The canal begins only a few miles from the old French and Indian portage

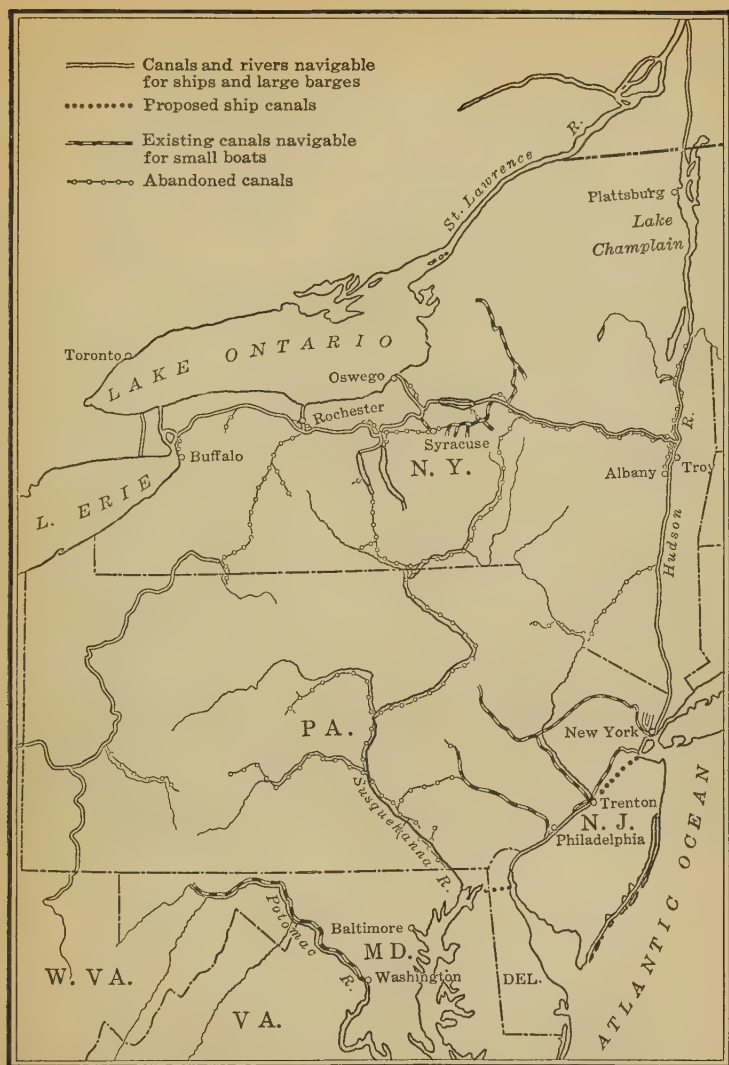


FIG. 106. The leading canals of New York, Pennsylvania, and New Jersey
Such a system offers large opportunity for inland transportation

and extends along the valley of the Des Plaines and Illinois rivers to La Salle, Illinois. It there enters the Illinois River. Thus the route used by the Indians for many centuries, and later

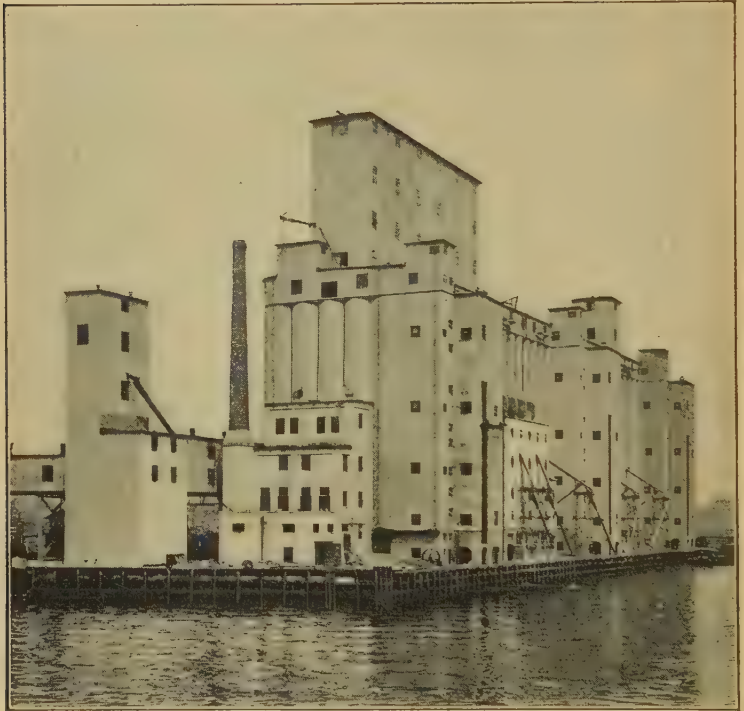


FIG. 107. A canal and railroad elevator

Grain transported slowly but cheaply by canals may readily be transferred to railroads or ocean-going steamships

by the French explorers, became the route of modern commerce, and a great city grew up about the site of the old fort.

Somewhat similar conditions made it possible to construct the Erie Canal, connecting the Hudson River with Lake Erie. This was the first canal made in this country, and it remains the most important. The rise of New York as our greatest port

and the growth of Buffalo were largely due to the great opportunities created by the Erie Canal (figs. 107 and 108).

207. Railroads. Soon railroads were built through the region about the south end of Lake Michigan, and the canal became less important. Two of the railroads were built along the route of early Indian travel. In the valley of the Des Plaines River, leading southwest, there are the river, the old canal, two railroads, a wagon road, a trolley line, and the sanitary drainage canal.

At the end of the lake was the only harbor in this vicinity where freight might be transferred between train and ship. The lake extends so far south that railroads built westward from the larger cities of the East toward the rich prairies of the West found their shortest route close to the end of the lake. Thus the settlement on the main line of pioneer travel came to be on the main line of railway travel.

Elsewhere upon the shores of lakes, rivers, and ocean the towns which were originally centers of commerce by water have become railway centers also. The importance of river commerce has decreased greatly since railways have become more numerous. In many cases the railways have followed the routes which were earlier used by water-borne commerce. Thus the New York Central Railway parallels the Hudson River,

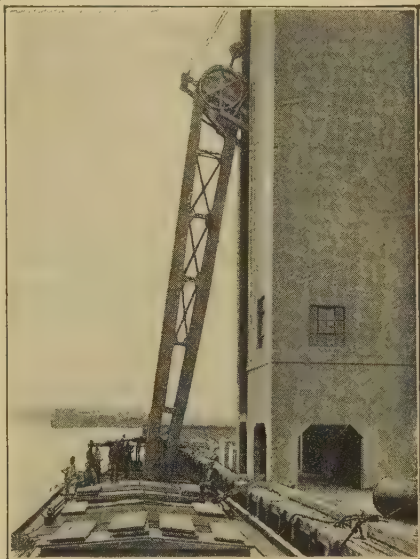


FIG. 108. Unloading wheat by use of a bucket-and-chain elevator

The wheat has been carried to this point in a canal barge

Erie Canal, and Lake Erie, and two railways follow the route of the Illinois and Michigan Canal.

208. Other cities. More has been said about Chicago than about other cities, since it is the largest city on the lakes and is the port closest to the heart of the country. It is therefore of interest to people in many parts of the United States. Very similar has been the history of other cities on the lakes, as Milwaukee, Detroit, Duluth, Toledo, Cleveland, Buffalo, or Toronto. The location and growth of most other large cities in the country, as well as of hundreds of smaller ones, are related to past or present water routes. St. Paul is at the head of navigation on the Mississippi River; New Orleans is near its mouth; St. Louis is near its junction with the Missouri; Cairo is near its junction with the Ohio. Kansas City marks the point where westward commerce formerly left the Missouri River to begin the long overland trip by the Santa Fe Trail, the California Trail, and sometimes the Oregon Trail also. Portland is an ocean port on the Willamette River, near its junction with the Columbia; Tacoma, Seattle, and other northwestern cities are on Puget Sound, and, like San Francisco, are located where the waters of the ocean penetrate the great valley behind the Coast Range of Mountains. On the Atlantic coast the greatest of our cities, New York, is located at the mouth of the Hudson River, which affords an excellent harbor. At the same time this river provides the easiest route through the Appalachian Mountains along our whole Atlantic coast; but all along this coast, or a short distance inland, are cities located on rivers which offer the same advantages in less degree. A study of those nearest your home should accompany the use of the above discussion.

209. Harbors, lights, buoys, and life-saving stations. A good harbor is a necessity for any city which carries on commerce by water. There must be some place where vessels may lie in quiet water while unloading or taking on cargo. Harbors need more or less constant dredging. They need properly constructed breakwaters to check the force of the waves and produce a fairly quiet area behind them in which vessels can lie in

security. Since the harbor is open to all vessels, it is the business of the government to make these improvements.

Lighthouses are placed at the harbor entrances and at other places to guide the pilot of a vessel safely into the harbor or to warn him of danger. Important lighthouses are equipped with foghorns, which are sounded at intervals of a number of seconds during rainy or foggy weather, when the lighthouse may not be visible. Obstructions, shallow places, and other dangers are commonly marked by buoys of different shapes and colors.

Life-saving stations are maintained at many places. Each station is in charge of a crew of trained and experienced men and is equipped with boats and other special apparatus for the saving of life in case of wrecks or other accidents. It is better, however, to prevent wrecks than to save life after a wreck, and one of the measures taken for this purpose consists in maintaining storm-signal stations, which are frequently connected with the life-saving station.

For those who live near oceans or lakes a study of the charts showing the harbors and the aids to navigation will be of great interest.

PART III. WORK, ENERGY, AND ELECTRICITY

CHAPTER XVI

COMMON TYPES OF WORK

210. Questions for discussion. 1. When a mountain stream wears away the stone and soil and carries them to a valley where they are deposited, is work being done? 2. May work be considered as constructive or destructive, wasteful or useful? 3. Why is it desirable, in using any kind of machine, to decrease the amount of friction? Why do we oil a bicycle, an automobile, a sewing-machine, or a farm wagon? 4. Can there ever be a truly automatic machine?

5. Why is there less friction in a machine with roller or ball bearings than in one with bearings of the usual type? 6. How does a set of pulleys enable a man to accomplish work which he could not accomplish unaided? 7. If a rope is arranged to run from a weight on the ground through a pulley attached to an elevated beam and down to your hand, will less force be needed to raise the weight than if no pulley were used? 8. Why is one's finger more likely to be crushed in a door if caught at the hinges than if caught at the latch?

9. When a long ladder is being raised, why must the lower end be braced against some heavy object? 10. How and when is water power used in getting the timber from the higher, hilly, or mountainous regions to the more level plains, or to sea level? 11. Can a boy kick a football harder by kicking it from a standing position or by running a few steps before kicking it? 12. Would two persons walking toward one another until they came in contact strike harder than when running toward one another?

13. What becomes of the energy of a moving train when the brakes are set? 14. If a piece of metal is pounded, or a piece of armor plate is struck by a cannon ball, the metal becomes hot. Why? 15. Why does a saw become hot when in use? 16. Does an auger heat more in soft or in hard wood? 17. Does a moving train possess energy after the engine driver shuts off steam?



OLD AND NEW WAYS OF USING WORK AND ENERGY

211. Work and machines. In the preceding chapter we have been considering one sort of work that is made necessary by modern civilization—the transportation of goods and people. Doubtless the first boat was a solid log with a savage sitting astride and paddling it with a stick or with his hands. Very early in history men learned to make boats and to propel them with paddles or oars. Among the best boats of ancient times were those made by the Romans. While both sail and oars were used to propel them, the swifter boats placed principal dependence upon oars. They were rowed by several hundred rowers, principally slaves and criminals sentenced to serve in the galleys. It was hard work, but except for the uncertain aid of the wind, no other way of driving the boats was known.

On land the work was accomplished in much the same way. The domesticated animals, such as the horse and the ox, were used for some purposes, but much of the work had to be done by the muscles of men. As the natural result slavery flourished, and many wars were conducted for the purpose of securing captives who could be used as slaves. The commerce of today on lakes, rivers, and oceans could not be conducted by the use of boats rowed by galley slaves, nor could modern land commerce be conducted by wagons pulled by horses and oxen. The transportation of goods is not the only nor the most important sort of work that is to be accomplished. Buildings must be constructed, trains moved across the country, and steamships driven across the ocean. Land must be plowed, crops planted, ditches dug, floors scrubbed, and lawns mowed. Work must be done every day in every way throughout the inhabited parts of the world. If the land were not plowed and planted and the crops harvested, there would be little for us to eat. If the trains and ships did not carry food for our great cities, many would starve. This has happened in countries like India, China, and Russia, where transportation facilities are not equal to the task of properly distributing the food that is produced in the country.

It is not possible for us to accomplish all these tasks by our unaided strength, and we must therefore use various machines

to assist us or to utilize the forces of nature. One of the great differences between savage and civilized men lies in the ability of the latter to help themselves in getting this work done (fig. 109).

212. Different methods of working. Primitive men doubtless did everything with their unaided hands. They soon learned that a heavy object could be pried up with a stick more easily than it could be lifted by the hands; that a sling would throw a stone harder than the unaided hand; that a log could be rolled up an incline if it was too heavy to be lifted; and that an arrangement of rope and pulleys would make it possible to hoist very heavy weights by the use of small force. Gradually the use of simple machines and combinations of them has developed, until now there is scarcely any work done without the use of some sort of mechanical contrivance. The simple machines, which are the basis of the devices which we employ to assist us in working, are the lever (fig. 110), the pulley, the inclined plane, the wheel and axle, the screw, and the wedge. These simple machines are employed whether we do the work by our own muscles or employ a horse or a steam engine.

The knowledge of the use of machines is of great value to civilized man. If we had been compelled to depend on bare hands and our own physical strength alone for accomplishing all sorts of work, our present civilization could not have developed (fig. 111). Our condition would probably be much like that of the tribes in those parts of Africa, Asia, and Australia where the soil is dug with a stick and goods are transported on the backs of men. The use of various contrivances which assist in the accomplishment of work, and the knowledge of their possibilities, are among the marks which distinguish civilized people from savages.

213. Understanding machines. Simple machines are so commonly employed and their use is so important that it is worth while for everyone to learn just what the advantages of machines are and how these advantages are secured. Once we understand machines we may be able to use them intelligently,



FIG. 109. Much undirected work has been done

The energy expended by water is enormous. Men are now learning to make this energy do useful work

and we may know just what can be expected from them. For instance, many men have expended a great deal of thought and money upon the effort to make a "perpetual motion machine," meaning by that an arrangement of such parts as levers, wheels, and axles, which when set in motion would continue to run

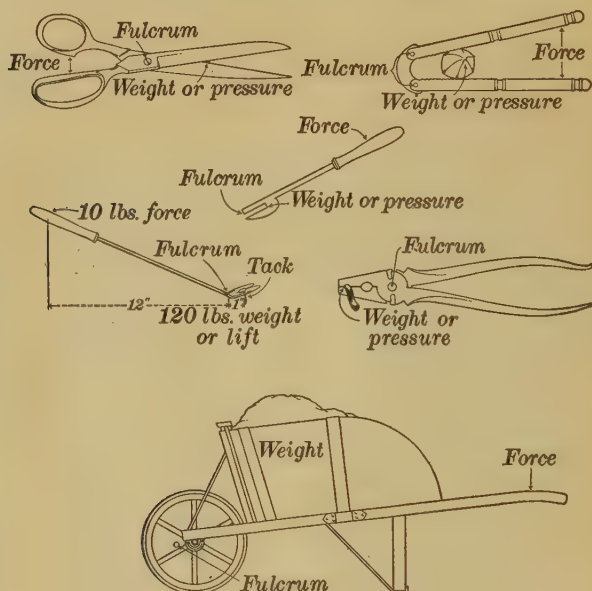


FIG. 110. Applications of the lever

The lever involves a weight to be lifted or pressure to be exerted, a force to be applied, and a fulcrum or pivotal point where the force works against the weight or pressure. Note the above and other applications of the lever, and discover what advantages are derived from it

indefinitely and also supply power to run other machines. When you have learned the principles of machines, you will see that perpetual motion in this sense cannot be accomplished.

214. Using machines. In order to get an understanding of the facts concerned with the working of a machine, let us state a definite problem and then see how it can be solved.

If workmen engaged in erecting a building wish a steel beam which weighs a thousand pounds raised to the upper part of the building, they would probably not carry it. Instead, they would probably raise it by use of a rope and pulleys. If they have two pulley blocks, each with two pulley wheels, the rope



FIG. 111. A few applications of the principles of modern machines, but not enough

would be threaded through somewhat as indicated in the diagram (fig. 112). In this diagram the pulleys are represented as separated in such manner that the rope or cord can be followed readily. What would be the advantage of using such an appliance? Just how many pounds of pull would be required to raise the thousand-pound beam? Are there any disadvantages in this scheme of work?

It might be inconvenient to locate a building where such work is being done, in order actually to measure the pull necessary on the end of the rope. It is easily possible to arrange a system of pulleys in the laboratory and by use of them to lift

a small weight, measuring the pull on the cord by means of a spring balance. If a thousand-gram weight is selected, the results can readily be compared with the case of the thousand-pound weight.

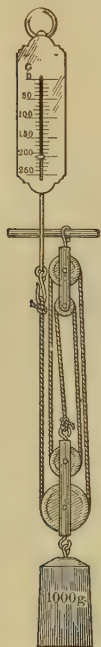


FIG. 112. Pulleys and cords

The pull on the cord is measured by the spring balance. The weight of the load is divided between strands of cord by which it is suspended. Disregarding friction, the pull on the spring balance will be one fifth as great as the pull that is exerted by the load

215. Some facts about pulleys. When an experiment is made in lifting a weight by such means as those suggested above, it becomes clear that the load is lifted by a much smaller force than would be needed if the pulleys were not used. It may not have been noticed that the distance through which the hand must travel when pulling on the end of the cord is much greater than that through which the load moves. The distances should be measured, and it will be found that when the load is raised a certain distance (an inch, for instance), the hand at the end of the cord must move five inches. The ratio is as 1 to 5. This is true, of course, only with the particular number of pulleys and arrangement of cord that are used in this experiment.

If one attaches a spring balance, graduated in grams, to the end of the cord (fig. 112) and by its means raises and lowers the weight, it will be found that when the weight is being raised the balance will indicate a pull of a little more than 200 grams. When the weight is being lowered slowly, the balance will read a little less than 200 grams. That is, the pull on the end of the cord that is necessary to support the weight is about 200 grams. Two hundred grams is one fifth of 1000 grams, and therefore the ratio of the pull to the load is 1 to 5.

We see, therefore, that the advantage in the use of this particular pulley system is that a given force applied at the end of the cord will raise a weight about five times as great as without the pulleys. This is called the mechanical advantage of the pulley system. It may be noted that the number of strands supporting the weight is also five. The mechanical advantage of a pulley system can always be learned by inspection, for it is always equal to the number of strands supporting the weight.

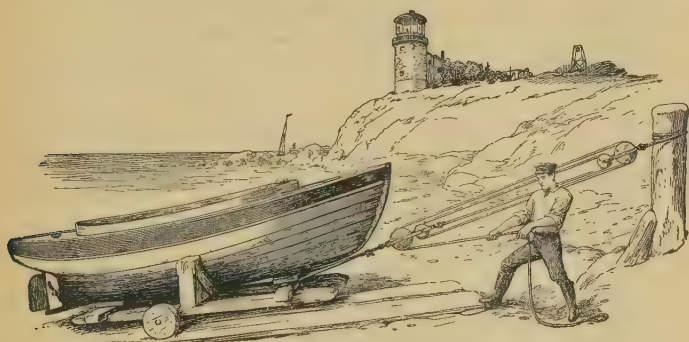


FIG. 113. The use of pulleys

By the use of pulleys, rope, and wheels one man may move a much greater weight than he could by pulling directly upon the object

While the weight can be lifted by the aid of the pulley system with one fifth the effort that would be needed without it, it must not be forgotten that the distance through which the cord must be pulled is five times as great. What is gained in the easier pull is lost in the greater distance. Usually we are more concerned about the force than about the distance, and therefore the pulleys are usually an advantage.

If in the case of the boat (fig. 113) the weight to be moved is 1000 pounds, how much force must the man exert to move the boat, assuming that friction is ignored? In the case shown in figure 114 are the two weights balanced? How much force must be exerted at the end of the cord where the 200-gram weight is, in order to raise the 1000-gram weight.

216. Friction. It will be remembered that in the experiment with the pulleys it was found that the pull needed to raise the weight was about one fifth of the amount needed to raise the weight without the pulleys. It was somewhat greater than 200 grams. The reason for this is that the pulleys offer some resistance in turning on their axles. This is due to friction between

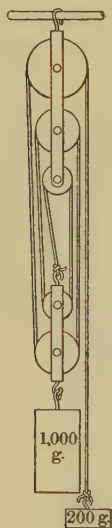


FIG. 114. Diagram of pulleys with weights at both ends of the cord

Do they balance?

the pulley and the axles, and the pull on the end of the cord must be equal to the pull necessary to lift the weight, plus that necessary to overcome friction in the pulleys and cord. If the pulleys are very well made and properly oiled, the friction will be very little, and the pull necessary to lift the weight will be very little more than 200 grams. It is impossible, however, to get rid of friction entirely. In pulleys such as we actually use, the pull necessary to raise the weight and overcome friction might very easily be as great as 250 grams instead of 200 grams.

217. Work defined. After all, when men raise a weight by means of pulleys, they do not escape doing work. In what way is the work different when the pulleys are used, and what is the real advantage of the use of pulleys? It is always necessary to be sure that we mean the same thing

by the words we use; therefore we should define work. We say that work is done when force is used to move an object any distance, as when a box is lifted from the pavement into a wagon or when a weight is pulled across the floor. Pushing the lawn mower, sweeping, pumping water, shoveling coal, are all forms of work, and in each case force is used to make something move against resistance.

218. Measurement of work. If a force of 1 pound is exerted in moving an object through a distance of 1 foot, it is plain that

a certain small amount of work has been done. This amount is called 1 foot-pound, and this is the unit of measurement. If the distance is increased two, three, or four times, the amount of work accomplished is increased proportionally. Likewise, the increase in resistance and therefore in force exerted is accompanied by a proportional increase in work. Thus, if 1 foot-pound of work is done in lifting a pound weight 1 foot, it should be clear that if the distance were 3 feet, 3 foot-pounds of work would be accomplished. If in the latter case the weight were 2 pounds, the work done would be 2×3 foot-pounds. That is, we calculate the work by multiplying the distance by the force.

Similarly, in the metric system the unit of work is the gram-centimeter, and it represents the amount of work done when a force of one gram works through a distance of one centimeter.

219. Calculation of work in pulley systems. We can now calculate the work done by men lifting a beam to place.

If the beam weighs 1000 pounds and is raised 25 feet, the work accomplished will be 25×1000 foot-pounds, or 25,000 foot-pounds. How much work do the men expend upon the end of the rope in accomplishing this result? According to the results of our small-scale experiment, it would be expected that they would have to exert a pull of about 250 pounds on the end of the rope. The rope would have to be pulled along five times as far as the beam was raised, or 125 feet. The work done would be 125×250 foot-pounds, or 31,250 foot-pounds. Is there a gain or a loss in the amount of work done by the men in using the pulleys?

220. Work with other machines. The principles applying to the use of all other simple machines are the same as those we have learned in the case of the pulley. In each case the force applied to the machine multiplied by the distance through which that force works gives the work put into the machine. The resistance of the load multiplied by the distance it was moved gives the work secured from the machine. Since there is always friction, the work put into the machine is always greater than the work secured from it.

221. Advantage in the use of machines. It should be clear from the preceding discussion that machines offer no advantage as to the total amount of work accomplished. We get nothing out of a pulley, lever, windlass, or any machine that we do not put into it. The usual advantage is that we are enabled to accomplish a task with a smaller force, though only by working through a greater distance and often for a longer time. Thus a very strong man might perhaps be able to lift a wheel of an automobile off the ground, but usually one person cannot exert enough strength to do this. A jack must be placed under the axle so as to exert enough force to raise the wheel. To raise the wheel an inch, your hand must travel a long distance back and forth. When you have raised it an inch, you have done as much work (and more) than a strong man would do in raising it an inch without the jack. The machine enabled you to apply your strength in such a manner that, with some loss of distance and time, you have accomplished a task that would otherwise be impossible.

Since every machine wastes some work in friction, it should be plain that the output of a machine must always be less than the input.

222. Capacity for doing work. In the experiments with the system of pulleys which were discussed in the preceding sections the force was applied at the end of the cord. The same results might have been obtained in another way. A weight of some sort might have been attached to the end of the cord. If this were of the proper size, it would, when released, descend and cause the load carried by the movable pulley to rise. It requires work to raise the load, and it therefore follows that the weight upon the end of the cord is able to do work. Also the pull upon the cord might have been supplied by an electric motor or by a steam engine. In either case the weight, the motor, or the engine demonstrates that it has the ability to do work. This ability, or capacity, to perform work is called energy.

The energy possessed by a weight in a condition similar to that in our last example is utilized in clocks which are run by

weights (fig. 115). In this case, when the clock is wound, the cord is wrapped on a small windlass and the weight is lifted. In this position it possesses energy enough to turn the wheels of the clock for some time. When the weight has reached the bottom of its descent, the clock must be wound again. Most modern clocks are driven by coiled springs, and in this case it is the tightly coiled spring that possesses energy. A sled coasting downhill possesses energy, as may be observed if it strikes any other object on the way; a cannon ball possesses energy, which is expended upon objects in its path; a moving hammer possesses energy, which may be utilized in driving a nail.

223. Kinds of energy. The weight in the clock possesses energy because of its position. When it is wound up and is suspended upon the cord, it is able to descend, and in doing so it will do work in turning the wheels of the clock. When the cord is unwound, the weight is not in a position to do further work. The energy which it possessed was dependent upon its position. The same is true of the bent spring, which possesses energy by virtue of the position of the parts of the spring in relation to each other. This energy of position is called potential energy.

On the other hand, the cannon ball does not owe its energy to position at all, but to the fact that it is moving rapidly. It is the moving cannon ball and not the stationary one that is effective for purposes of destruction. The hammer and the sled also owe their energy to motion. Energy of motion is called kinetic energy.

224. Measurement of energy. Since energy is simply the capacity to do work, it can be measured in the same units as are used to measure work; that is, energy is measured in foot-pounds.

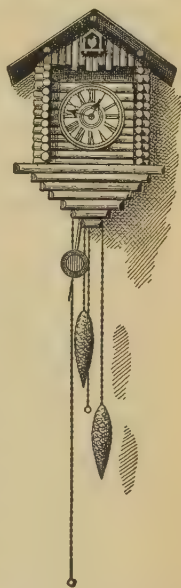


FIG. 115. A clock run by weights

A 5-pound weight at a height of 2 feet possesses $5 \times 2 = 10$ foot-pounds of energy, since in order to place it there a force of 5 pounds had to be applied through a distance of 2 feet. Thus the energy which a body possesses is in general equal to the work which has been done upon it.

225. Work against friction produces heat. It is a common experience that heat is produced when work is done against friction. Anyone who has attempted to break a wire by bending it back and forth has had occasion to know that it becomes very hot at the place of bending, and the harder and longer one works, the hotter the wire becomes. The same thing results from hammering a nail, and a saw becomes much heated when in use, particularly if there is much friction. If a wheel is allowed to run for some time without oil on the axle, the latter becomes very much heated. When a match is rubbed on a smooth surface, it is lighted by the heat which is produced by friction. Primitive people started their fires by use of friction between two pieces of wood. In all these cases work is done, and a part of its result appears in the form of heat.

226. Energy transformed into heat. Careful studies have shown that in cases like the above the amount of heat developed is in proportion to the amount of energy lost in overcoming friction; that is, it is proportional to the amount of wasted work. In lifting a weight by means of pulleys a part of the energy which is exerted at the end of the rope goes to the direct raising of the weight and makes its appearance in the form of potential energy in the weight which has been lifted. But, as noted before (Sect. 216), part of the work done goes to overcome friction and is lost as useful work. It has not gone out of existence, however, for it now makes its appearance as heat. The amount of heat produced in operating a machine is not very great if the machine is well oiled and in good condition. If the work is heavy and the operation is rapid, a very high temperature may result, as when an ungreased wagon wheel becomes hot.

227. Work done by heat. It seems a very unfortunate thing that so much of the work that we do is changed into heat and

is thus ineffective in accomplishing our purposes. However, there is something to be learned from it. If energy can be changed into heat, as we have seen, is it possible that heat might be changed into useful energy and caused to do work for us?

It was only about two hundred years ago that this question was first answered for us by the invention of a machine that would make heat do work. That machine was the steam engine. Most of us have not been used to thinking of the steam engine as a heat engine, but if we think over the facts that we know about engines we shall see that this is really true. What is the source of energy in a steam engine? The things that a steam engine, such as a railroad locomotive, needs in order to keep working are water and coal. The steam which comes from the engine may be condensed into water and used over again, as is commonly done for steamship engines. In this case the water is merely a permanent part of the machine, and it cannot be the source of the energy. The coal is the only remaining possible source of energy, and it is quite useless unless it is burned to supply heat to the boiler. Heat from any other source is just as effective. That is, if heat is supplied to the boiler in sufficient quantity, we shall be able to get work out of the engine; if heat is not supplied, no work will be done. We therefore see that work can be done by heat, and the steam engine is a device to accomplish this.

The steam engine is one of the most important inventions of the human race, because it has relieved man of so much work. At the present time, steam engines are probably doing 200,000,000 horse power of work throughout the world. This is much more work than could be done by the combined muscular effort of the workers of the world unaided by these machines. If we did not have engines, a lot of work would not be done; but so long as we have means of producing heat we can keep the engines at work.

It is important and worth while to find just how the steam engine does its work. This will be discussed in the following chapter.

228. The source of energy. It has been shown that heat has the ability to do work ; but we defined energy as "ability to do work." It therefore follows that heat is a form of energy. Where does the energy come from? It comes from the coal, or it may come from wood or any other inflammable material. The coal therefore contains energy, but how did it get into the coal?

Those who have studied the origin of coal tell us that it is formed of the remains of plants of former ages. The plants grew, and their dead bodies accumulated in great abundance in some places, somewhat as plant materials are accumulating now in our peat swamps. These swamps were buried by sediments which later became rocks. The plant material was buried far enough to be affected by the heat of the interior of the earth, and it was under great pressure from the rocks lying over it. All these things caused it to condense into a solid, stonelike mass which does not at first look much as though it were made up of dead plants. A full account of the origin of coal cannot be given in this connection, but the subject will prove most interesting as an accompanying study.

Of course if there is energy in the coal, it must have been in the plants from which the coal was made. We can burn wood to make steam in about the same way that we can burn coal. Indeed, wood is still sometimes used as fuel under boilers. Where, then, did the plants get their energy? Where do they get it now? When we were studying about how plants make their food, we found that they could do so only when they had light. Light is the power that runs the factory. By means of the energy that comes to it in the form of light, the plant is able to separate the carbon from the oxygen of the carbon dioxide and to build up those complex compounds from which its body is constructed. When we burn the wood, oxygen again unites with the other elements to form carbon dioxide, water, and other compounds, and, most important to us, the energy that was put into the compound is released in the form of heat.

The sun, then, is the source of the energy which we find stored up in wood and in coal. If we were to take any other

example and trace back the energy, we should in all cases arrive at the sun as the last term in our series. The sun is the great source of the world's energy.

229. Amount of energy from the sun. Some careful studies have been made to find out how much energy the earth receives from the sun. It is believed that the amount is equivalent to more than 200,000,000 horse power for each inhabitant of the earth. It is this continual supply of energy from the sun that maintains the temperature of the earth's surface, evaporates water, causes air currents, and provides the energy for photosynthesis. Since the earth is continually giving off heat to the surrounding space, it is continually losing energy. The part of the sun's energy which is stored up in plants and animals, or used in evaporating water, supplies most of the energy which is used by man in accomplishing his work.

It has been found that the energy that falls upon an acre of ground during six hours of sunshine is equal to that which would be produced by burning 16.4 tons of coal. The energy received by an acre of wheat during a growing season of ninety days would thus be equivalent to 1476 tons of coal. Little of this energy is stored up by the wheat plants; for when the crop is reaped, it is found that its energy value is less than that of a ton of coal.

Since plants use and retain so little of the energy which reaches them from the sun, about 1 part in 2000, many attempts have been made to construct "solar engines" to be operated directly by the energy of the sun's rays. None of these have been successful on a commercially profitable scale.

Of course only a small part of the energy given off by the sun comes to the earth,—1 part in 2,000,000,000,—and therefore the sun must be giving off energy very rapidly. Perhaps its supply of energy is growing less, but it is so big that the loss has not been great enough to be noticed during the short time that men have been making careful observations of the sun. Although the sun must finally lose so much energy that it will not be able to give off as much heat and light as it does now, it is

estimated by astronomers that a sufficient change to affect life upon the earth will not take place for many thousands of years.

230. Energy and work in living things. Many of the instances of work which have been given in the preceding chapters are examples of work accomplished by living beings. If you climb a flight of steps, push a lawn mower, or saw a board, you are doing work; you are expending energy. Even when you are sitting still or when you are sleeping, there is some expenditure of energy, for the heart continues to beat, you continue to breathe, and heat is radiated from your body. The lower animals expend energy in similar ways. Plants too use energy, for they open and close their flowers, move their leaves, lift large quantities of water from the soil to the leaves, and engage in many other activities. Energy is supplied to living things through food somewhat as energy is supplied to a steam engine through the agency of the coal which is put into the furnace. Since the origin of foods can be traced back to the manufacture of carbohydrates through the aid of the sun's energy, it is not difficult to see that the sun is the ultimate source of energy for all the activities of living things.

Somewhat later, and in another connection, we shall give more attention to the sun, the source of all energy and therefore of all life, but just now we must study in more detail the steam engine and other means by which we may utilize available energy to do our work. Among the most important of these devices are the various electrical appliances which are so very important in modern civilized life.

CHAPTER XVII

STEAM ENGINES AND GAS ENGINES

231. Questions for discussion. 1. Water becomes heated when it is used to cool a gasoline engine. Does this represent a waste of energy? 2. What are the principal wastes of energy by a gasoline engine? 3. Coal has sometimes been called preserved sunshine. In what sense is this true? 4. Would it be possible to use steam, gas, or electric engines if work that has been done by the sun were not available?

5. From what mineral and by what process are gasoline and kerosene obtained? 6. Name two products of combustion which result from the burning of gasoline or kerosene. 7. Explain the meaning of the following expressions: (1) good mixture; (2) lean mixture; (3) rich mixture. 8. By examining an engine how could you tell which is the inlet valve and which is the exhaust valve? How do they operate? 9. What purpose does the flywheel of an engine serve?

10. Explain how the cylinders of any one make of automobile engine are kept lubricated. 11. Why is it necessary to crank a gas engine in order to start it? 12. State whether a fuel vaporizes more or less readily (1) if it has a high boiling point; (2) if the weather is cold; (3) if the engine is hot. 13. Why do drivers frequently close the choke valve in starting the engine? Why does the driver need to open the choke valve again as soon as the engine starts?

232. The steam engine. The machine commonly called a steam engine (fig. 116) really consists of two principal parts—the steam engine proper and the boiler. The engine and boiler may be very closely connected, as in the railway locomotive, or they may be located at considerable distance from each other, as in some manufacturing establishments or on board ship, where they are usually in different rooms. In the boiler, water is changed into steam by means of the heat supplied by the fire in the furnace. This steam is conveyed through a pipe to the parts of the engine where the energy is changed from heat into the mechanical energy of moving parts.

The more important facts regarding the structure and operation of a simple engine may be understood by referring to the diagram, figure 117. The essentials of a steam engine are a cylinder, *C*, containing a tightly fitting piston, *p*, together with some means to control the admission of steam into the cylinder. The piston is free to move from end to end of the cylinder, and as it moves, the connected piston rod, *r*, moves with it. With the parts in the position indicated in the diagram, if steam from the boiler is admitted through the pipe *st* into the steam chest, *S*, it will pass through the channel *ch* into the cylinder. Here

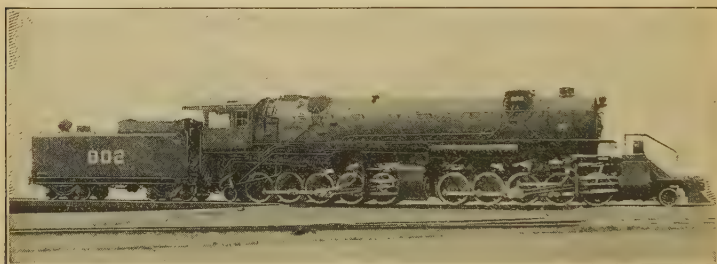


FIG. 116. Steam in gigantic iron harness

Very powerful for use or for destruction, depending upon whether it is understood and properly controlled by trained men

it will exert pressure upon the piston and drive it to the other end of the cylinder. Steam which may have remained in the opposite end of the cylinder from the previous stroke escapes from in front of the moving piston through the channel, *ch'*, under the slide valve to the exhaust pipe, *e*, which leads into the open air or into a condenser. A working engine is so arranged that when the piston reaches the position indicated by the dotted lines, the slide valve, *s*, is moved into the position indicated by dotted lines. This, it should be noticed, prevents the steam from passing into the right-hand end of the cylinder, while at the same time it admits it to the opposite end. The pressure of the steam on the other side of the piston drives it back toward the end of the cylinder from which it started.

When the piston again reaches the end of the cylinder, the slide valve returns to its original position, and this action is repeated for each stroke of the piston.

The moving piston may be connected to machinery which is to be operated. The work which is done by the piston upon the machinery is derived from the steam as it expands in the cylinder. The steam which leaves the exhaust outlet, having parted with some of its energy to the piston, is no longer as hot as it was when it entered the cylinder.

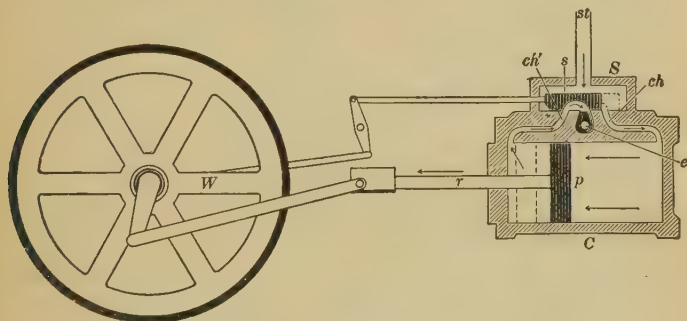


FIG. 117. The working parts of a simple steam engine

W, flywheel; *C*, cylinder; *S*, steam chest; *st*, steam pipe from the boiler; *ch*, *ch'*, passages for steam between steam chest and cylinder; *s*, slide valve; *p*, piston; *r*, piston rod; *e*, exhaust pipe.

Since water in the form of steam is continually passing from the boiler to the engine, the amount of water in the boiler decreases unless more water is supplied. Some boilers are supplied with water by a force pump which may be operated by the engine. Another appliance used for the same purpose is the injector, which uses steam from the boiler to force water into the boiler.

In many steam-power plants the exhaust steam is condensed and pumped back into the boiler. This method has several advantages, among which may be mentioned the facts that the condensed steam is already hot, and that it does not contain the impurities that are sometimes found in water from wells and streams.

233. Transformation of energy. There are other forms of energy besides heat and mechanical energy, but we shall not discuss these at any great length. Both electricity and light are sources of energy; and potential or kinetic energy may be transformed into heat, light, or electric current. The steam engine, together with some of the machinery that it may drive, furnishes a good illustration of the many possible transformations of energy. Suppose that the engine is driving a dynamo and that the electric current which the dynamo generates is employed in operating a number of lights. In that case we may start with energy in the form of heat contained in the steam. In the engine cylinder a portion of the energy is imparted to the moving piston, and this energy no longer appears in the form of heat. The energy in the moving piston is transmitted to the dynamo and is there transformed into a current of electricity. We therefore speak of an electric current as a form of energy. The current is passed through a lamp in which it gives off its energy in the form of light and heat. This energy passes off into the surrounding space and is usually lost.

234. Loss of energy. The amount of heat and light energy that is secured from the lights is not at all equal to the amount of heat energy that was produced by the coal burned in the furnace to operate the dynamo. It may be no more than 5 per cent of the total produced by the coal. Plainly there has been a very great loss somewhere along the route that the energy has traveled in passing from the furnace to the light. This loss is not difficult to find. A great deal of heat goes up the chimney, some radiates from the boiler and engine into the air, and some passes off in the exhaust steam. In these and other ways the steam engine wastes possibly 85 per cent or more of the energy produced by the coal. Of the energy actually utilized by the engine some is lost by friction in the engine and dynamo, showing itself in the form of heated bearings, and some is lost through the heating of the wires by the currents of electricity. Notice that in all these cases of lost energy the energy is not destroyed. It changes into some form in which it

is not useful to us (usually into the form of heat which may warm the surrounding air), but it has not gone out of existence.

There is no way known by which we can destroy energy.

There is no way known by which we can create energy.

235. Gas engines. In later years the place of the steam engine has been taken in part by the gasoline engine, and the latter is also employed in many kinds of service to which the steam engine is not adapted. A gasoline engine is much lighter than a steam engine capable of delivering the same power, and the fuel which it requires for a given amount of work is lighter also. It can therefore be used more satisfactorily on automobiles, aeroplanes, and in other places where lightness is desired. Gasoline engines that weigh no more than two pounds per horse power are constructed for aeroplane work.

The modern type of gas or gasoline engine was invented about 1876. The gasoline automobile came into general use between the years 1900 and 1910, and the great improvement of the gas engine has in large part made possible the rapid development of the automobile industry (fig. 118). Since 1910 the number of automobiles employed for commercial purposes as well as for touring has increased with great rapidity. The manufacture of automobiles has become one of the world's leading industries (see table, p. 217). In town and country the motor car, the gas engine, and the tractor are indispensable in our daily lives.

The construction and use of gigantic steam engines and of millions of automobiles have compelled attention to new types of roadways over which these modern machines may run (fig. 119). It is not probable that the problem of road-building for modern uses has been finally solved.

236. The gas engine operated by heat. The gas engine lacks the boiler, fireplace, and smokestack that we have come to associate with the steam engine. There is no visible burning of fuel, and so little smoke that one readily gets the idea that the gas engine is not a heat engine operated by the burning of fuel, as is true of the steam engine. However, the gasoline engine is, like the steam engine, driven by the expansion of highly

heated gases, but in this case the fuel is burned inside the cylinders and therefore out of sight. For that reason engines of this type, whatever the fuel used, are called internal-combustion engines.

237. Burning a mixture of air and gas. For experiments to demonstrate the expansive force of burning gases it will be more convenient to mix illuminating gas with the air than to

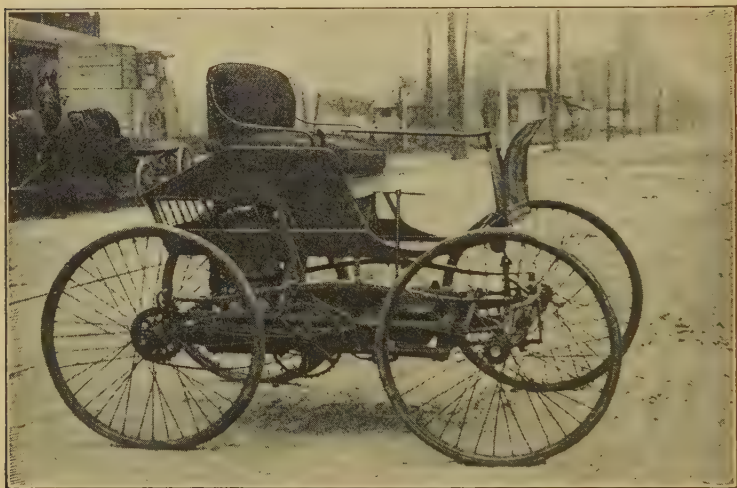


FIG. 118. The first automobile

This "gas buggy" or "horseless carriage," as it was called, built by Elwood Haynes, represents an early stage of one of the world's most remarkable accomplishments in mechanical use of heat energy—the modern automobile

use gasoline and air, since it would be necessary first to vaporize the gasoline. The gas may be collected in a wide-mouthed bottle over water, as was done with other gases in previous experiments (Chapter IX). If the bottle is filled completely with pure gas and placed on the table, the gas will burn only sluggishly around the mouth of the bottle when a match is applied. This slow burning is caused by the fact that the gas is mixed slowly with the oxygen from the surrounding air.

NUMBER AND VALUE OF MOTOR VEHICLES MANUFACTURED
EACH YEAR IN THE UNITED STATES: PASSENGER CARS AND
TRUCKS

YEAR	NUMBER	VALUE
1899	3,700	\$4,750,000
1904	21,700	24,581,000
1910	185,000	223,000,000
1911	210,000	262,000,000
1912	378,000	378,000,000
1913	485,000	444,000,000
1914	569,000	459,000,000
1915	892,000	691,000,000
1916	1,583,000	955,000,000
1917	1,868,000	1,274,000,000
1918	1,153,000	1,236,000,000
1919	1,892,000	1,807,000,000
1920	2,205,000	2,233,000,000
1921	1,669,000	1,260,000,000
1922	2,527,000	1,559,000,000

NUMBER OF AUTOMOBILES IN USE IN THE UNITED STATES
EACH YEAR FROM 1912 TO 1922

YEAR	NUMBER
1912	1,033,000
1913	1,288,000
1914	1,769,000
1915	2,480,000
1916	3,585,000
1917	4,992,000
1918	6,106,000
1919	7,597,000
1920	8,932,000
1921	10,450,000
1922	11,500,000

NOTE. The number of automobiles registered for the entire world in 1922 was 12,750,000. The automobile registration fees for 1921 in the United States exceeded \$122,000,000. The gasoline consumption in the United States for 1922 was 5,300,000,000 gallons.

Again, if the bottle is filled half full of gas and removed from the water, allowing air to bubble in as the remaining water runs out, we get a mixture that is half air and half gas. This mixture will burn somewhat more rapidly, but there is no sign of an explosion.

If the experiment is repeated a number of times, increasing the proportion of air each time, it will be found that as the air

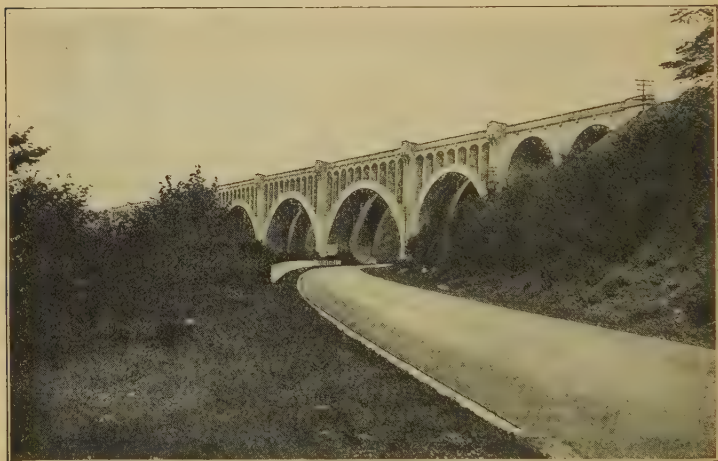


FIG. 119. Modern roads and bridges for modern machines

Concrete road for automobiles, and reënforced concrete railroad bridge

is increased, the burning is more rapid and finally is accompanied by a report and other signs of explosive violence. About four fifths of air and one fifth of gas will be found to be the mixture producing the most violent explosion. When more than four fifths of air is introduced into the mixture, the explosion is weakened or fails altogether. When the mixture is properly proportioned, the oxygen necessary to burn the gas is mixed with the gas, and the burning is practically instantaneous. The explosive force is due to the expansion of the gases by the heat produced.

This effect sometimes occurs accidentally when gasoline

evaporates in a room and becomes mixed in the proper proportions with the air of the room. Then when a match is struck, an explosion occurs. Gasoline should never be permitted to evaporate in a closed room.

When a properly proportioned mixture of gasoline vapor and air is burned or exploded in the cylinder of an automobile engine, at the instant of explosion the temperature of the gases in the cylinder suddenly rises to about 2500° F. Owing to the tendency to expand, resulting from this great heat, the gases may exert a pressure of from 250 to 300 pounds per square inch at the moment of explosion. At this rate of pressure the force against a piston surface of ten square inches would be as much or more than 2500 pounds. In the engine of a well-known light automobile and other engines of medium size the pressure on the piston at the moment of each explosion is about a ton. In large cars and trucks the pressure may be as much as two tons, depending upon the area of the face of the piston.

238. Gas-engine problems. The several problems that one must solve in order to secure an understanding of the gas engine are these: How is the explosive mixture brought into the cylinder? How are the gasoline and air properly mixed and proportioned? How is the mixture ignited? How are the heated gases removed from the engine after they have done their work? To understand these things it is necessary to find out what are the mechanical parts of the engine and how they operate.

239. Mechanical parts of a gas engine. Among the important parts of a gas engine are the following: *a*, cylinder; *b*, piston; *c*, inlet valve; *d*, exhaust valve; *e*, connecting rod; *f*, crank shaft; *g*, fly wheel; *h*, cam shaft. All these parts can be identified in the illustration (fig. 120). The piston moves up and down in the cylinder as the crank shaft revolves. The cylinder and piston must be well lubricated to prevent leakage of gas and to avoid excessive wear on the metal of the cylinder wall as well as on the piston itself. The intake valve and the exhaust valve are each opened by a cam on the cam shaft which opens then at the proper time. They are closed by strong springs.

240. Drawing in the explosive mixture. Suppose that the engine is standing with the piston at the top of the cylinder and that the inlet valve is open (fig. 120). If the engine is turned by hand, the piston will move downward in the cylinder. This increases the space inside the cylinder and allows the air within to expand, in this way reducing the pressure. Since the

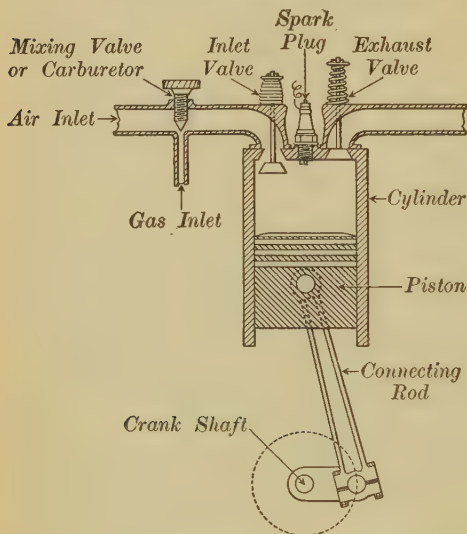


FIG. 120. Mechanical parts relating to the gas cylinder

pressure inside the cylinder is less than it is outside, the atmospheric pressure will drive air into the cylinder through the tube that leads to the intake valve. If the proper amount of gasoline vapor is added to the air as it passes in, the cylinder will be filled with an explosive mixture of air and gasoline vapor.

About the time the piston reaches the lowest point in its travels and starts

upward, the intake valve is closed and the mixture is trapped inside. As the piston moves upward to the topmost position the mixture is compressed to about one fourth of its original volume. When the piston is at the topmost position and the cylinder above it is filled with the compressed gases, if the mixture is exploded, the piston will be driven downward with great force. Thus the engine will be in operation under its own power.

241. Exploding the mixture. The compressed gases in a gas-engine cylinder are usually exploded by an electric spark. The manner in which a spark plug operates may be illustrated by

connecting an induction coil, or spark coil, and batteries with the plug (fig. 121), but this should be done only by one who is familiar with the danger from such coils. The connections should be made as in the diagram. More detailed attention will be given to the electric system of an automobile in a succeeding chapter.

242. The carburetor. To produce a mixture of air and illuminating gas is easy, since both are gases. Gasoline is a liquid and can be mingled with air only with some difficulty. It must first be vaporized. It is well known that if gasoline is exposed to the air it will slowly evaporate, and the vapor will diffuse through

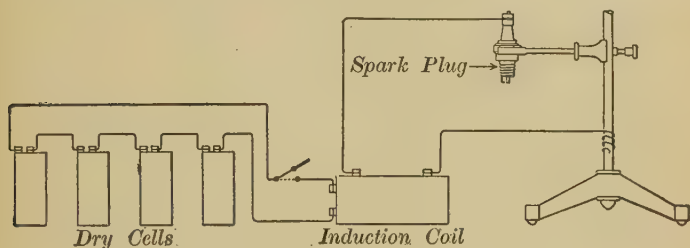


FIG. 121. Spark plug and electric current

the air. As mentioned in a preceding paragraph, this sometimes occurs when gasoline is exposed to the air in a room, and when a sufficient amount of the vaporized gasoline has mingled with the air of the room the mixture is explosive. In the operation of a gasoline engine it is not possible to allow the gasoline to evaporate slowly, since it must be vaporized and mixed with the air during the time required for the moving piston to draw in a charge of the mixture. When the engine is running, the time involved is but a fraction of a second.

The proper mixing of gasoline with air is secured by means of the carburetor. The principle of a simple carburetor is shown in figure 122, but it must be remembered that a practical working carburetor has many details not shown in this figure.

In figure 122 the air passes through the air inlet tube on its

way to the cylinders of the engine, as described in a preceding section. Into this tube projects the end of another tube leading from the gasoline chamber. When the pressure is reduced in the air passage around this tube by downward movement of the piston in the cylinder, the pressure of the outside air drives the air through the passage toward the cylinders. In like manner the pressure of the air on the surface of the gasoline in the gaso-

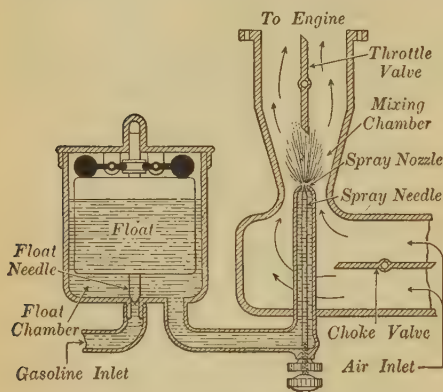


FIG. 122. The carburetor and its parts

line chamber forces the gasoline through the pipe and out of the small opening or spray nozzle at its end. This opening is so formed that the jet of gasoline breaks up into a spray and is thus distributed through the current of air. The small drops of gasoline evaporate rapidly, particularly if evaporation is assisted by heat. Most modern

engines are provided with some means of heating the air that enters the carburetor. In some cases there are also means provided to heat the air passage between the carburetor and the engine or to heat the gasoline in the chamber.

The gasoline chamber contains a float which, as it rises, closes a needle valve and thus shuts off the supply of gasoline from the tank when the chamber is filled to a certain level. This is necessary in order to prevent flooding the carburetor with gasoline. The spray needle is used to adjust the flow of gasoline to the spray nozzle so that the right mixture shall result.

The many details that have been added to make the modern working carburetor are mainly intended to secure the best possible spray of gasoline and to insure the proper mixture at all speeds and all throttle openings. The ways in which this is

accomplished are best studied in special books on this subject and by examination of carburetors.

243. The exhaust. In the preceding sections we have seen how the explosive mixture is drawn in by the downward movement of the piston and compressed by the upward movement. When the piston is at the top and the mixture is compressed above it, the spark causes the explosion, and the piston is forcibly driven downward. While the heated gases resulting from the explosion are expanding and forcing the piston downward, both intake and exhaust valve must be closed so that none of the force of the expansion may be lost. When the piston has reached the bottom of the cylinder and starts up, these confined gases would hinder the movement of the piston, and they must therefore be allowed to escape. For this purpose the exhaust valve is opened (fig. 123, *D*) and allows the escape of the burned gases into the exhaust pipe, which leads to the open air.

Since gasoline is a compound consisting principally of carbon and hydrogen, the products resulting from the perfect combustion of gasoline are carbon dioxide and water. However, the combustion of the gasoline in the motor is rarely complete, and there is commonly formed not only carbon dioxide (CO_2) but also carbon monoxide (CO). This latter gas is very dangerous whenever it is present in the air in any considerable quantity.

244. Dangers from carbon monoxide. When air containing carbon monoxide is inhaled, this gas unites with the red blood corpuscles, making them incapable of carrying oxygen. This soon results in unconsciousness and may result in death from oxygen starvation.

In the open air the proportion of carbon monoxide never rises high enough to be considered seriously dangerous. If a gasoline engine is exhausting into a restricted space, as when an automobile engine is allowed to run in a closed garage, the carbon monoxide very soon becomes dangerous to life. A person working in such places has no warning of its presence until stupor begins to affect him, since carbon monoxide is wholly odorless.

By the time the victim realizes his danger he is commonly so far overcome that he is unable to make his way to the open air. Because of this danger of carbon-monoxide poisoning, a gasoline engine should never be operated in a closed room unless there is provision for conducting the exhaust gases out of doors.

Carbon monoxide may also be given off by any apparatus which burns illuminating gas. All gas-heating apparatus should be arranged with connection to a chimney to remove the fumes. If this is not done, the heating apparatus is a menace to life.

245. The four strokes. It will be noted that in the operation of a cylinder of a gas engine there are four strokes, corresponding to two revolutions of the crank shaft. The first downward motion of the piston is known as the intake stroke (fig. 123, *A*), the return of the piston to the uppermost position is the compression stroke (fig. 123, *B*), the pushing of the piston down again by the explosion is the power stroke (fig. 123, *C*), and the return to the top as the burned gases are driven out is the exhaust stroke (fig. 123, *D*). Such engines are often called four-cycle engines.

From the figure it can be seen that in a one-cylinder gas engine one power stroke occurs in each four strokes, or one power stroke in two revolutions. An engine of this type cannot fire for every revolution. If two cylinders are used side by side, they may be made to fire alternately, and thus one explosion is obtained for each revolution. If four cylinders are used, as in some automobiles, they are so arranged that one of them fires every half-revolution. In other words, a four-cylinder engine has two power strokes per revolution, a six-cylinder engine has three power strokes per revolution, and an eight-cylinder engine has four power strokes per revolution.

246. The cooling system. The temperature of the burning gases in the engine is very high, as mentioned before (about 2500° F.). Unless means are taken to cool the engine it will become almost as hot as the gases. Such a high temperature would destroy the oil used for lubricating the cylinders and pistons and injure the metal itself. It is therefore necessary to arrange

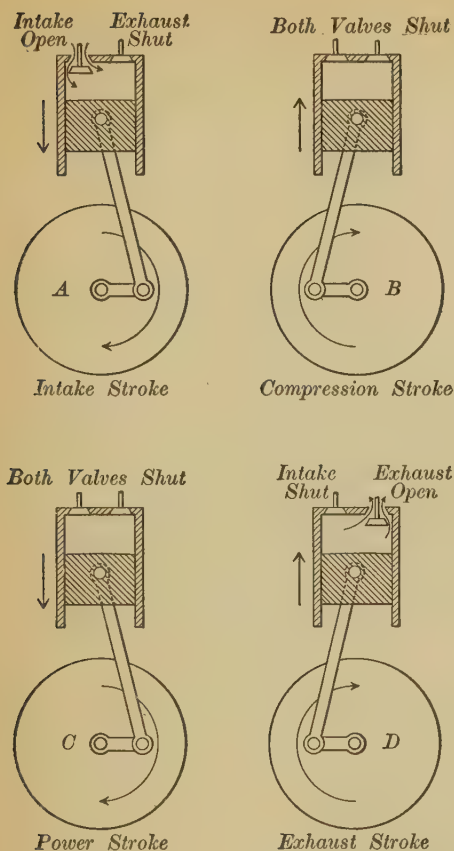


FIG. 123. The four strokes of each cylinder

A, downward stroke, gas entering; B, upward stroke, valves closed, gas being compressed; C, gas has exploded, piston is going downward, power being exerted on crank shaft; D, upward stroke exhausting burned gas

means to keep the engine sufficiently cool. This is usually accomplished by circulating water around the cylinders and through a radiator in which the water is cooled. In some engines the cooling is accomplished by circulating air around the cylinders.

Since the gas engine is a heat engine, it is clear that all the heat carried off by the water and radiated into the air represents a loss of energy, but this loss is unavoidable. Care should be taken, however, that in cold weather the engine shall not be allowed to radiate more heat than necessary, since an engine that is kept too cold is wasting energy.

247. Transmission of power in automobiles. In an automobile engine the chemical energy of explosion causes the impulse against the

piston, the piston transmits its power to the connecting rod, and the connecting rod causes the engine crank shaft to revolve.

Between the crank shaft and the rear wheels the power is transmitted through the following parts: the flywheel, the clutch, the change-speed gears, the universal joints, the propeller shaft (or driving shaft), the differential, the rear-axle shafts, and the

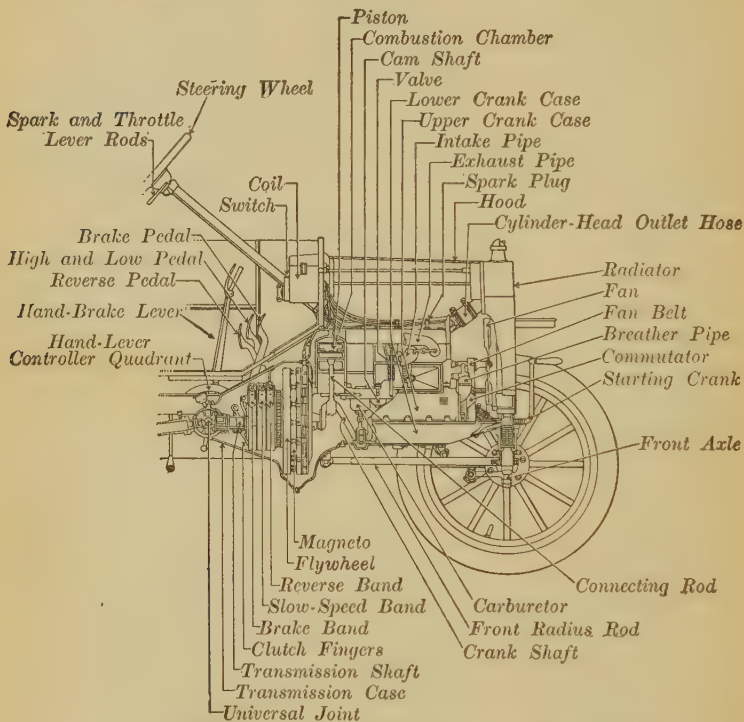


FIG. 124. The parts of the front portion of a light automobile

rear wheels. Diagrams are given in figures 124 and 125 by means of which those who wish to do so may become acquainted with the locations and names of the chief parts of the running gears of automobiles.

248. The flywheel. Since the power is transmitted to the crank shaft by explosion, the motion of the crank shaft would be irregular and jerky if the engine were operated without the

heavy flywheel. A heavy object has great inertia, which means that it cannot be stopped easily or suddenly, nor can it be started suddenly. The flywheel gives to the engine greater inertia and causes it to operate with a steady motion.

249. The clutch. The clutch is a device which provides for disconnecting and connecting the engine and the drive shaft. The clutch is usually located in or next to the flywheel and between the crank shaft and the gears. The clutch is also disconnected in shifting gears.

250. The gears. Automobiles are usually equipped with gears which are toothed wheels of different sizes and are contained in the gear case. These gears are so arranged that when the driver shifts the gear lever, gears of different sizes are meshed, resulting in increasing or decreasing the speed of the drive shaft and the rear wheels, which are the drive wheels. The combinations ordinarily provided for are "high," "medium," "low," "reverse," and "neutral." For high gear no gears would be needed, because the drive shaft revolves at the same rate as the engine crank shaft. In going up a steep hill, however, low gear is needed to obtain a greater pulling force. In this case the gears provide for a slower rate of speed in the drive shaft than in the engine crank shaft. By this means greater pulling force for climbing the hill is obtained, but at the expense of car speed.

251. The differential. When a vehicle turns a corner the wheel on the outside must travel a greater distance than does the inside wheel, hence it must revolve faster. The rear axle, therefore, cannot contain a one-piece shaft extending from wheel to wheel. If the rear-axle shaft were a single piece, one wheel would have to slip in making a turn. The differential gears make it possible for one half of the axle shaft to revolve at a rate different from that of the other half when the car turns a corner.

252. The brakes. The rear wheels of automobiles are usually equipped with metal parts called brake drums. Sometimes all four wheels are so equipped. The brake bands extend

around the drum. If a band compresses against the outside of the drum, it is called a contracting brake; if it compresses against the inside of the drum, it is called an expanding brake. Each brake drum commonly has two bands, a contracting band on the outside and an expanding band on the inside. These bands are operated by a system of levers and rods from the foot pedal and the hand-brake lever. The inside band is commonly used for the emergency brake, or hand lever; the outside band for the service, or foot, brake.

253. Lubrication. The life of the automobile engine as well as of the transmission mechanisms depends largely upon proper lubrication of all friction surfaces. Pistons, connecting-rod bearings, crank-shaft bearings, and many of the minor parts of the engine must have a constant supply of lubricating oil of proper grade. Some clutches are designed to operate in oil. The gears, the differential, the axle bearings, and other parts require heavier grease.

In the less expensive engines the pistons and the cylinder walls receive their oil by the splash system, in which the connecting rods dip into a pool of oil which stands in the bottom of the crank case. Many engines have oil pumps and pipes which carry a constant supply of oil to the principal friction surfaces. In caring for an automobile constant attention should be given to the oil supply. If the pistons and bearings operate with insufficient oil or with oil of poor quality, the piston surfaces and the cylinder walls will rapidly wear away, and the engine will soon leak compression, waste fuel, and lose power.

254. Automobile fuels. Two fuels have been widely used for producing power in automobile engines, gasoline and benzol. Kerosene and the heavier oils do not vaporize as readily as gasoline, but they will burn in certain types of engines. Poor vaporization results in a deposit of carbon on the cylinder walls, pistons, valves, and spark plugs. Both gasoline and benzol are compounds of carbon and hydrogen. They vaporize readily. Gasoline is obtained by distilling petroleum. Benzol is obtained by distillation from coal or coal tar. Until recently

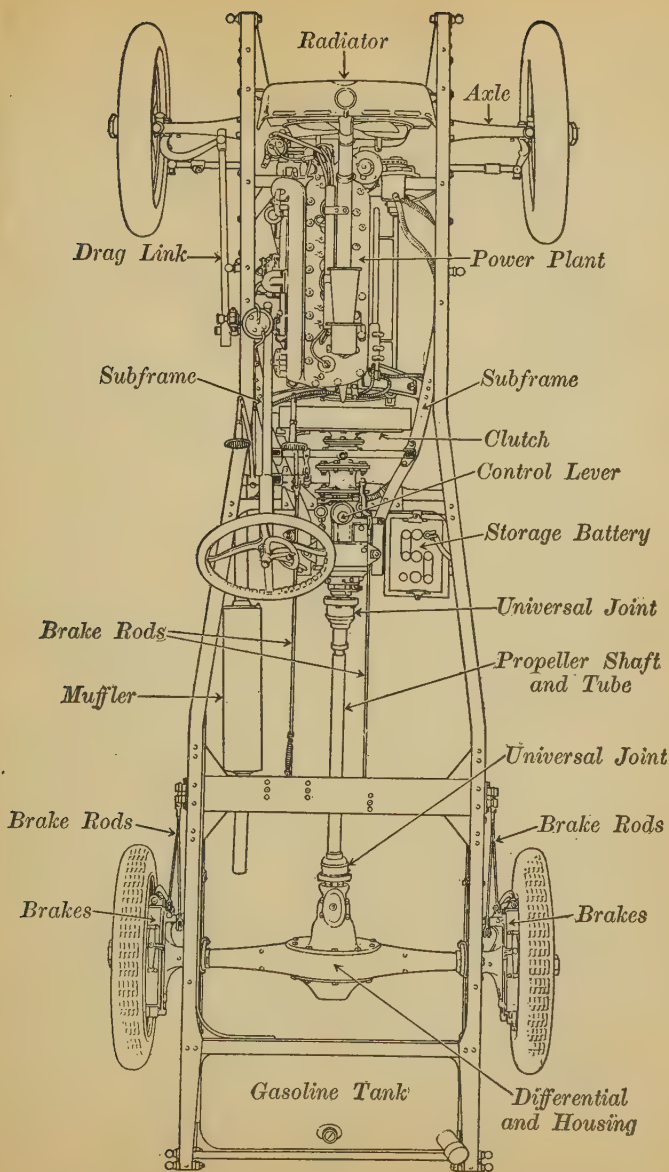


FIG. 125. The chief parts of the chassis of an automobile

benzol has been used chiefly in European countries on account of the scarcity of gasoline. Experiments indicate that other engine fuels will be commercially available for gas engines.

Automobile engines may also be operated with alcohol. However, alcohol has not been manufactured cheaply enough as yet to compete with gasoline and benzol. Alcohol or gasoline is sometimes mixed with benzol to make the benzol more volatile. Alcohol is made from vegetable materials, and because of this the supply can be readily increased. It may become necessary to utilize alcohol as an engine fuel when the world's petroleum and coal reserves have been consumed. At the present alarming rate of coal and gasoline consumption, the supply will be exhausted in a comparatively few years unless new deposits of these valuable minerals are developed.

255. Gasoline distilled from petroleum. Gasoline is obtained from crude petroleum. Petroleum is a mixture of a great many oils which have different boiling points. The petroleum is heated in huge retorts or stills containing between five hundred and one thousand barrels of crude oil. As the temperature of the petroleum rises the different grades of oil vaporize, beginning with those which have the lowest boiling points and ending with the heavy oils having high boiling points. The vaporized or distilled gases are condensed in pipes surrounded by cold water. The first distillates are sometimes grouped together under the name of the naphthas. Then, when the temperature is raised to about 250° F., the distillation product is gasoline. At a higher temperature kerosene and the illuminating oils are vaporized.

The remaining products, after the more easily vaporized substances are removed, contain the heavier oils. By refining these heavy oils many grades of lubricating oils are obtained, including vaseline and paraffin wax.

The proportions of the different distillation products vary widely in different crude oils. Some crude-oil fields supply petroleum which contains a relatively high proportion of naphtha and gasoline, while the petroleum from other fields contains chiefly the heavier oils used for lubrication.

The following table shows the approximate boiling-point temperatures of some important petroleum products:

	BOILING POINTS
Light distillates	30 degrees to 100°F.
Naphtha	80 degrees to 120°F.
Gasoline	90 degrees to 200°F.
Kerosene	300 degrees to 500°F.
Lubricating oils and fuel oils	500 degrees to 700°F.
Vaseline	600 degrees to 700°F.
Paraffin wax	700 degrees to 800°F.

256. An experiment with kerosene. A further study of the fuel characteristics of these substances may be made by using the lid of a baking-powder can on an asbestos mat. The mat

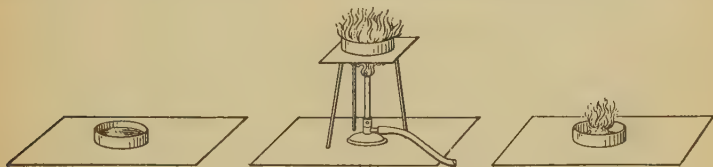


FIG. 126. An experiment with kerosene

should be about two feet square. About five cubic centimeters of kerosene should be placed in the can lid (fig. 126). A laboratory apron or other large cloth should be available for use in case it is needed for smothering a fire. When a match is applied to the kerosene in the metal dish it will not burn, because the boiling point of kerosene (from 300° to 500° F.) is so high that at ordinary temperatures very little vapor is given off—not enough to produce a flame. However, if the metal dish is placed on a tripod over a wire gauze and heated gently with a Bunsen burner, the kerosene will then vaporize more readily, and the gas which is given off may be ignited directly with a match.

If a small ball of cotton or cloth is thrown into a dish of cold kerosene, and the cotton or cloth is then ignited, the burning material soon causes some of the kerosene to vaporize and burn. This suggests the function of the wick in a kerosene lamp or

in a kerosene stove. Kerosene is sometimes used for operating gas engines. It is difficult to vaporize kerosene thoroughly and to maintain it as a gas. Unless the engine is hot the kerosene tends to condense to a liquid. Fuels do not burn in the liquid state. If gasoline were used in the metal lid instead of kerosene, its vapor could be ignited directly with a match, because its boiling point is so much lower than that of kerosene that a sufficient quantity of gas is evaporating from it to produce combustion.

257. Automobiles and economy. Modern life has been greatly changed owing to the development of the gas motor and its accompanying machinery. This change is well shown by brief reference to the automobile. That automobiles are more convenient than horses and wagons is readily shown, and sometimes they have reduced costs. One large department store, which twenty years ago paid \$990 per day for delivering goods with horses and wagons, has reduced its costs for this service to \$350 per day by use of automobiles. Many contractors, plumbers, tinnerns, salesmen, craftsmen, and tradesmen of all kinds find the automobile more economical and infinitely more effective than were the horses and wagons of former days.

It has been estimated that 1 horse requires about 5 acres of land to produce its food, and the 20,000,000 horses said to be in the United States therefore require 100,000,000 acres of land. This means as much land as the states of Ohio, Indiana, and Illinois combined. If only half of the horses of the country could be replaced by automobiles and farm tractors, about 50,000,000 acres of land might be released for other purposes.

258. Automobiles and education. About one farmer in three now has an automobile. The farmer who formerly had time to travel five miles by horse and buggy can now go thirty miles in the same time by automobile. The farmer's wife can now go to town more frequently, visit friends, attend church and social clubs, and use the public library as well as other agencies for education and recreation. By this saving of time and enlarging of opportunity the automobile relieves drudgery and

contributes to greater efficiency and happiness. In rural communities the automobile now makes possible the transportation of pupils many miles to a large and well-equipped central school, thereby eliminating many small and relatively less effective rural schools. Even the veterinary surgeon must now use an automobile when called to the country to save the life of a horse, and the family physician is readily available in a short time in any country home.

By encouraging travel and social communication the automobile contributes to education in the broadest sense, thereby placing the advantages of the city within the reach of the rural communities and vice versa. The automobile has become an agency for educating its owner in a very specific way. To operate his car intelligently and economically he must make a thorough study of its mechanical parts. He must learn their functions and their underlying principles. He must learn to perform mechanical operations with accuracy, to draw reliable conclusions, to make adjustments, and to test the results. That this has not been properly learned as yet is shown by the fact that in one year eleven thousand deaths were caused in the United States by automobile accidents, and that property damage from this cause reached \$1,000,000,000. It is clear that people must learn better how to use modern gas motors, as well as other modern machinery, if the greatest good is to be derived from the applications of modern science.

CHAPTER XVIII

SOME COMMON USES OF ELECTRICITY

259. Questions for discussion. 1. What are the sparks sometimes observed between the trolley wire and wheel? 2. Why are electric wires often put in metal pipes? 3. Why are glass insulators used on telephone and telegraph lines? 4. Which is cheaper to operate, a tungsten or a carbon lamp? Why? 5. Why are electric-lamp wires covered with rubber and cloth? 6. Are electric-heating devices expensive to use as compared with devices which use coal and gas?

7. How should dry cells be connected for a doorbell circuit? 8. How does a push button operate the electric bell? 9. Is there any danger in having electric wires in a house? 10. How is electricity brought to and distributed throughout a residence? 11. How is a flashlight battery made? 12. What is a fuse? Why is it used?

13. Why are ammeters used on automobiles? 14. How can telephones be protected from damage by lightning? 15. What is a short circuit? 16. Is a short circuit dangerous? 17. What does electric energy cost in an ordinary residence? in a store? 18. How is an electric iron constructed? 19. How is the electric current supplied to street lamps?

260. Importance of electricity. We have come to depend very much upon electricity as a convenient form in which energy may be transferred and applied. Electrical appliances may turn the machinery of our factories, take us from place to place, transmit messages over wires or without wires, wash and iron our clothes, sweep the rugs and carpets, cool us in summer and warm us in winter. Electric current lights our dwelling-houses more brilliantly than does any other source of artificial light. Automobiles, the most common means of transportation, use the electric current in many ways (fig. 127).

261. An electric circuit and switch. An important beginning problem will be to arrange wires so that a lamp may be lighted

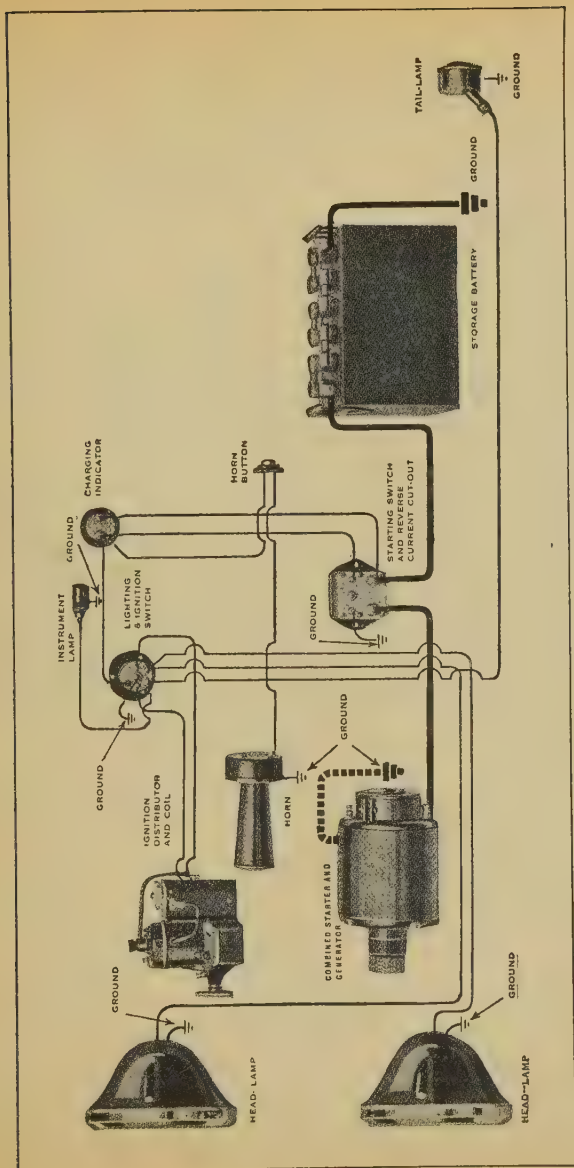


FIG. 127. Automobile electric circuits connected with storage battery

and means provided whereby the light may be turned on and off as desired. For this experiment a proper source of current must be provided. The best source to use experimentally is a battery of six dry cells connected as illustrated in figure 128. A toy transformer makes a very satisfactory source of current for the lighting experiments.

Lamps appropriate for use in the experiment are automobile-lighting bulbs of the "double contact" type. If possible secure several automobile-lamp sockets (double contact) and mount them on a large drawing-board in such a position as to represent automobile headlights. Then try to light one of the lamps by running wires across the board from the battery to the lamp. It will be found that the lamp is lighted when the wire extends from each terminal or binding post of the battery to the connections of the lamp. Trace the possible path of the current from one pole of the battery through the socket and lamp and back to the other pole. A complete path for the current is furnished through conductors from the battery through the wire, socket, lamp, and battery back to the starting point. Such a complete path is called a circuit. An electric current operates or flows only when the circuit is complete.

The circuit should be traced through the lamp itself. In a double-contact bulb trace the wire from one contact into the bulb and out again to the other contact point. A discarded and broken bulb will be satisfactory for this use.

Since a complete circuit is necessary, the lamp may be turned off by breaking the circuit at any point, as by loosening one wire from the battery. Such a method is effective, but it is not always safe, and is never so satisfactory as is a special device for breaking the circuit. A switch is usually placed in a circuit. This is merely a device by which the circuit may be readily broken or connected.

Many kinds of devices for opening and closing circuits are in use, but the common ones are the knife switch (fig. 128) and the automobile-lighting and house-lighting switches. The way in which each of these works should be determined.

262. How the lamp makes light. If a closer examination is now made of the lamp when the current is turned on, it will be seen that the light comes from a length of wire which makes part of the circuit through which the current flows, and that this wire gives off light because it is white-hot. The electric current heats the wire and thus produces the light.

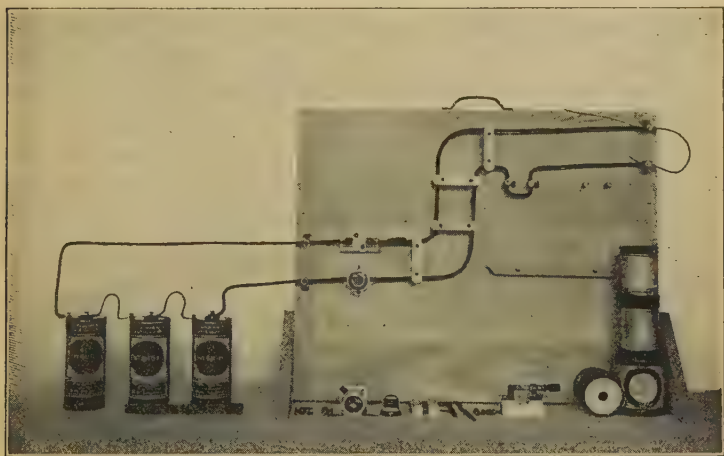


FIG. 128. Apparatus for study of an electric circuit

The handmade mounting board with porcelain cleats, binding posts with screws, and switch provides a simple and effective means of studying electricity. The electric generator consists of three dry cells connected by insulated copper wire. At the right, above, is a loop of small wire fastened to the binding posts so that the heating effect of electricity may be studied; at the right, below, are four spools of wire of different sizes for use in the same experiment

Why is the one particular part of the wire within the bulb heated while other parts of the circuit—even within the lamp—are not heated? Again, examination of the wire in the lamp gives a suggestion for explanation. It is easily seen that the wire which gives off light has a smaller diameter than any other wire in the whole circuit. This suggests that the heating effect is related to the diameter. This may be tested by using a piece of fine wire as part of a circuit (fig. 128) with six dry cells as

the source of current. No. 30 copper wire, which is one hundredth of an inch in diameter, is suitable. By varying the length of the piece of wire it will be possible to heat it to any desired degree up to the melting point. About three feet of wire will be required for the experiment.

Heat may be produced in any part of the circuit, and the size of the wire is an important factor in producing it. It is true, also, that the kind of metal composing the wire affects the amount of heat produced, but as copper is almost always used for electric circuits the effect of differences in the composition of wires need not be studied now.

263. Heat in the circuit. The amount of heat produced in a wire depends in part on the material of which it is composed, in part upon the amount of the current flowing, and in part on the size and length of the wires. It follows, then, that some heat will be produced in all parts of the circuit. If the wires are large enough to carry the current used, the heat will not be noticeable, or it may make the wires only slightly warm.

264. Dangers from overheated circuits. With wires properly installed and used there is no danger of damage from overheated wires, but if they are not rightly arranged and used, much damage may result. For example, the wiring system of an automobile may be supposed to be correct when the car leaves the factory, but sometimes changes or repairs are made. If in this case smaller wires are used, or if more lights are added so that the current used is too great for the wires to carry, they will become heated and may set fire to adjacent parts.

One way in which very large currents are allowed to flow through wires is by the formation of short circuits, or "shorts." If you were to lay a piece of metal across from one wire of the circuit to another in your experimental lighting circuit, most of the current would take the easier path through the piece of metal instead of going through the lamp. If two bare wires of a circuit come into direct contact the same thing would happen. In either case a very large current would flow, resulting in heating the wires and possibly melting them.

Short circuits are avoided by covering the wires with substances which do not readily carry the current (called insulators), such as rubber, cotton, or silk. Mica, porcelain, and dry wood are also insulators. However, insulation is sometimes rubbed off of wires, and they may come into contact with each other or with such objects as the frame of an automobile, the metal parts of a house, or its wet woodwork.

265. Protection of wiring systems. Wires may be protected from danger of damage to insulation and resulting short circuits by inclosing them in metal tubes or conduits. This has the further advantage that if the wire should become heated from any cause, it is so inclosed that it cannot set fire to anything. All electric wires in buildings, automobiles, or motor boats should be inclosed in this manner.

Another method of guarding against damage from the passage of too large a current on a circuit is by the use of fuses.

266. The use of fuses for safety. In the electric circuit there is a piece of soft metal in the fuse plug (fig. 129, *D*) which makes an important use of the heating effect just discussed. The current in the circuit must pass through this piece of fuse wire, which is a mixture of lead and tin or other metals. If the current becomes excessive the metal melts and thus breaks the connection, but the melting occurs at a very much lower temperature than would injure the wires of the circuit. This fuse is therefore a sort of "safety valve" in the electric circuit. Fuse wire is made and labeled in various sizes so as to limit the strength of the current to whatever may be desired. Such fuses are often found near the electric meters in a building. They may be observed, but should not be disturbed.

The open-link fuse (fig. 129, *A, B, C*) is often unsatisfactory because drops of molten metal deface the supporting board and may injure the operator. Another type of fuse contains a metal wire or strip which can be renewed, but this is covered with a tube of fiber (fig. 129, *E, F*). Telephones are also protected by fuses (fig. 129, *H*). All electric circuits and the appliances in them should be protected either by fuses or by automatic

switches which open before the current reaches a strength that will do damage. The rules of insurance companies require that they shall not take risks upon buildings that are improperly wired. For experimental work it is wise to use a fuse which is rated much lower than the current which the instrument can

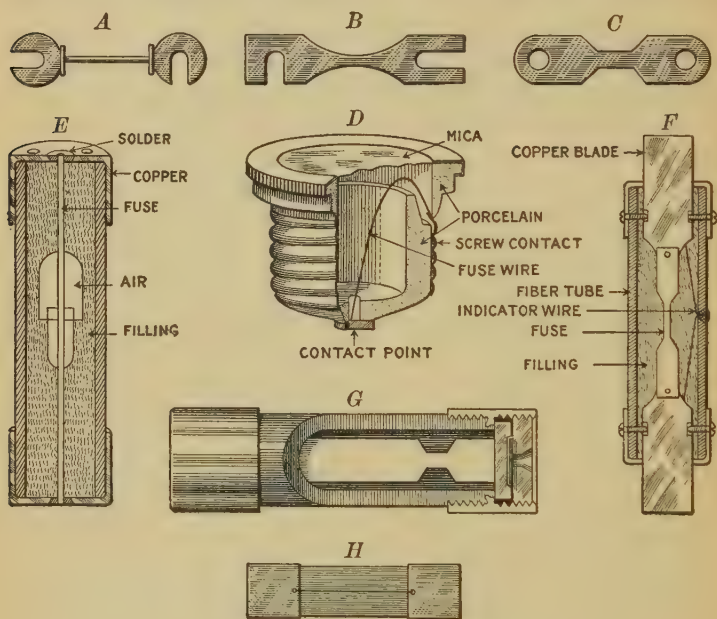


FIG. 129. Different types of fuses

A-C, simple fuses designed to hook over connecting posts; *D*, an ordinary screw-plug fuse; *E-H*, fuses to be slipped into fuse openings so that the fuse ends connect with electric wires

carry safely, since certain fuses often carry a momentary current from 50 to 100 per cent greater than the rated value marked on the label.

When the currents become very large, as those required for street-car motors or commercial machinery, a device called a circuit breaker is used. This is essentially an automatic switch

which opens, often with considerable noise, when the current reaches the limit which has been set for it.

267. Connecting additional lamps. In the original experiment (Sect. 261) only one lamp was put into the circuit, but in practical lighting, whether on an automobile or in a house, several lamps must be used. How are more lamps to be added?

There are two ways in which the connections may be made. The wires may be so arranged that the current must pass through first one and then the other lamp in series, or it may be so arranged that it can divide between the two. The first is called series connection; the second, parallel connection. Try both ways of connecting a second lamp, and note the results.

Electric lamps intended for home or automobile use are almost universally made to operate in parallel connection. An indefinite number may be operated in this manner if the diameter of the wires leading to the lamps is great enough and the current is sufficient. Any one of the lamps may be used independently of the others.

In some special cases series connection is used in operating lights. The tungsten lamps or the arc lamps on the street are usually connected so that the current flows through each lamp in succession, and they are said to be connected in series. Decorative lamps for Christmas trees are also connected in series. The chief objection to this kind of circuit is that if one lamp breaks, none will give light.

268. Measuring the current. The current flowing through a circuit may be measured by an instrument called an ammeter, which is familiar to us on the instrument board of an automobile. The units which are shown on the face of the ammeter (fig. 130) are called amperes.

An ammeter should be put into the experimental circuit in

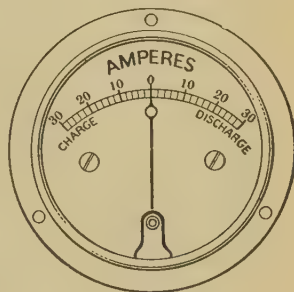


FIG. 130. An ammeter

series with one of the lamps, and the current used by the lamp should be measured (fig. 131). The following precaution should be observed: An ammeter must never be connected directly across the terminals of a battery nor placed in a circuit in any way excepting in series with a lamp or some other appliance. Lamps of different sizes may be used, and additional ones may

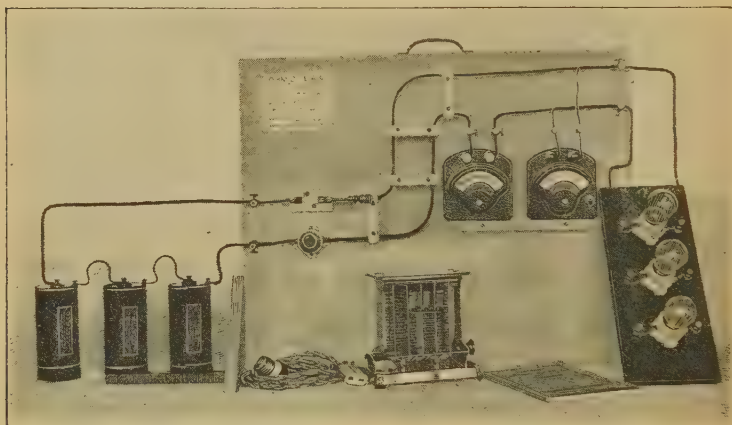


FIG. 131. Series and parallel connections

The strength of current (amperes) is read from the ammeter on the left, the electrical pressure (volts) from the voltmeter on the right. The sign lamps shown are rated at eleven volts. The electric toaster is made of high-resistance wire or ribbon

be connected in series and in parallel (Sect. 267). It will be found that if the lamps are connected in parallel, each additional lamp will add to the current used and will not cause the other lamps to become dim; if connected in series, each additional lamp will cause a decrease in the brilliancy of the light and a decrease in the amount of current flowing.

269. Efficiency of lamps. In all experiments with electric lamps a good deal of heat is given off; in fact, sometimes a bulb becomes too warm to be held in the hand with comfort. Since the lamp is used to furnish light, the heat is not useful and may sometimes be undesirable. The heat given off by the

lamp represents just that much of the energy of the electric current wasted instead of being made into useful light. However, no one has yet been able to devise a lamp which would give light without heat. Even in the best types of bulbs used for lighting, only about 5 per cent of the energy is given off as light, while the remaining 95 per cent is wasted as heat.

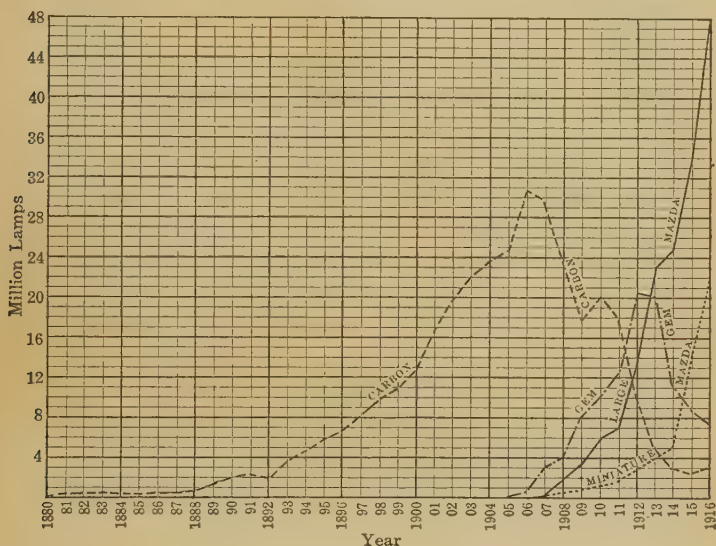


FIG. 132. Use of incandescent lamps

270. Kinds of lamps. The very low efficiency of the incandescent electric lamp has led to many attempts at improvement. At the present time electric light is more expensive than many other kinds of illumination, but if a lamp could be devised which would give light with but little waste in heat, electric lighting might be much cheaper.

The first type of incandescent lamp to be used was invented by Thomas A. Edison in 1879 (fig. 132). The electric current was passed through a piece of charred bamboo fiber which was heated by the current. The burning of the filament was pre-

vented by exhausting the air from the bulb, producing a vacuum. The carbon lamp had a very low efficiency. About 1894 a method was discovered for improving the carbon filament. Lamps having a metal filament were introduced about 1906, and these are so much more efficient that they have almost wholly displaced other types. The metal used in the filaments of modern lamps is tungsten. The principal advantage in the use of tungsten is that it may be heated to a very high temperature without damage and therefore gives off more light. The melting point of tungsten is above 3600°C. , or 6500°F.

Many of the tungsten lamps in common use for house lighting are vacuum lamps, but it has been found that lamps with the bulbs containing nitrogen have a higher efficiency than vacuum bulbs. The vacuum bulbs are cheaper and are commonly used in house lighting, but the gas-filled bulbs are becoming more popular in homes, and are commonly used for store and street lighting. For automobiles nitrogen-filled bulbs are used almost entirely.

In some cases bulbs are made from a special blue glass in order that the light which shines through the glass may have as nearly as possible the qualities of sunlight. This is important wherever it is desirable to recognize colors by artificial light. Lamps are made also with milk-white glass bulbs. The white glass serves to hide the bright filament from the eye and to diffuse the light. The filament of an incandescent lamp should never be exposed so that it can shine into the unprotected eye. The bulb should be made of white glass, or, better yet, the lamp should be inclosed within a large white shade.

271. Conductors and resistance. Substances along which electricity readily flows are called conductors. Those which do not conduct electricity or conduct it but slightly are called insulators. Common insulators, including those already mentioned, are rubber, cloth, mica, glass, porcelain, dry air, and dry wood, while the metals and carbon are conductors. Electricity does not flow along all conductors with equal ease. In fact, all conductors offer some resistance to the flow of the current, the

amount varying according to the material of which the conductor is composed, its diameter, and its length. Copper wire is a very good conductor. That is, it offers very little resistance to the passage of the current, while nichrome¹ wire, as used in flatirons and toasters, offers great resistance to the passage of the current. In fact, the resistance of nichrome wire is about sixty times as great as the resistance of copper wire of the same diameter.

† The amount of heat produced in a conductor is in proportion to the resistance if other factors are constant. Thus it is dangerous to use a fine copper wire to carry the current to the headlights of an automobile, because the fine wire, offering considerable resistance to the flow of the current, may become very hot, while a coarse wire would not be noticeably heated. A nichrome wire, even though considerably larger, might be dangerously heated.

Copper offers less resistance than any other substance commonly used for electrical conductors. The only other metals with resistance nearly as low as that of copper are aluminum, silver, and gold. Aluminum is now sometimes used in place of copper.

The precautions to be observed are that one should always use for conductors a metal with low resistance (preferably copper), see that the wires are large enough to carry any current likely to be desired, and see that the wires are properly installed. The principal household devices that call for a large current are electric irons and electric stoves. Further information is given in the table on page 268.

272. Electric-heating devices. While the heat produced by electric lamps is undesirable, since it represents wasted energy, there are many common devices which are constructed to utilize the heat given off by the electric current. A common implement of this kind is the household smoothing iron. This iron (fig. 133) is much more convenient for those whose homes are provided with electricity than are irons heated by other methods. Furthermore, the electric iron when in use is kept constantly at the

¹ The name suggests its composition of nickel and chromium.

desired temperature, so that there is a saving of the time usually consumed in changing or reheating the iron when coal or gas is used as the source of heat. Because of these advantages, as well as the increased cleanliness, electric irons are coming into common use in commercial laundries and clothing establishments as well as in private homes. Care must be taken not to

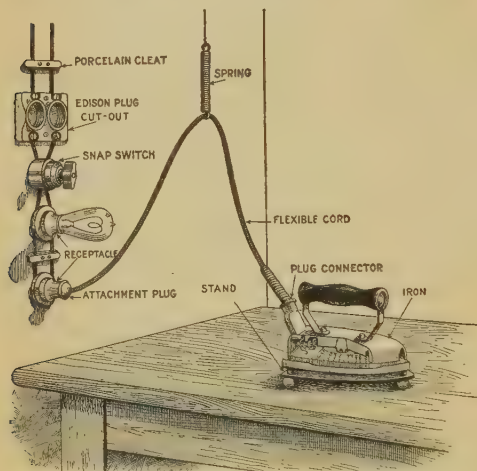


FIG. 133. An electric flatiron

The resistance wire shown in the iron is heated by the current. Devices are also shown for attaching the cord for use of a lamp, for turning the currents on and off, and for attaching fuse plugs

allow the current to flow when the iron is not in use. It is possible to start fires in this manner.

Some other electric heating devices which are coming into use are soldering irons, glue pots, radiant heaters, toasters, tea-pots and coffeepots, and cooking stoves. In every case the heating element is a wire of such high resistance that it is heated by the passage of the current.

These wires are visible and may be examined in such appliances as electric toasters, but in smoothing-irons and many other devices they are inclosed and cannot be observed without injuring the instrument.

273. The dry cell and its uses. Dry cells are frequently used as the source of electric current. The dry cell (fig. 134, A) consists of a zinc can which contains a rod of carbon surrounded by a mixture of black manganese dioxide and powdered carbon. Within the zinc can is a paste of sal ammoniac (ammonium

chloride) and water. The ammonium chloride solution or paste is the most important material in the cell, but the manganese dioxide and powdered carbon are necessary for the best operation. In the zinc of an old dry cell many holes may be seen. Most of the metal has disappeared, since it has been consumed by chemical change to furnish the energy to drive the

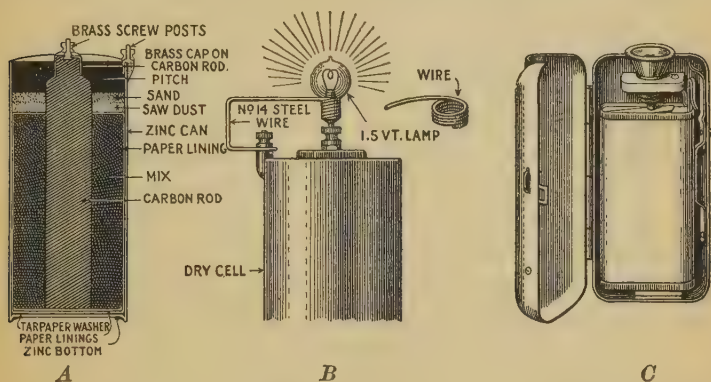


FIG. 134. Dry cells

A, longitudinal section of a dry cell; *B*, simple flashlight which uses a dry cell; *C*, pocket flashlight similar to *B* except that it is inclosed

electricity through the cell and the circuit, somewhat as coal is burned to furnish the energy used in pumping water through pipes. An old dry cell may often be improved for a short time by punching a hole in the top and adding water.

Zinc is an expensive material to use as a source of energy. For this reason dry cells are commonly used only where small, intermittent currents are desired, as in the case of doorbells, toys, clocks, telephones, spark coils, and flashlights. Dry cells of the usual size are now manufactured in the United States at the rate of more than fifty millions each year. Great quantities of smaller cells are used in flashlights and radio sets.

274. Electromotive force. Nothing has been said so far about what makes the electric current flow. When water flows through

a system of pipes we recognize that it flows because of the pressure supplied by pumps or gravity. In somewhat similar fashion electricity flows through the wires because of the electric pressure produced by the battery or dynamo. Water pressures are measured in pounds per square inch; the unit of electric pressure is called the volt. The term "electric pressure" is not commonly used; instead, we call it electromotive force and measure it in volts.

The electromotive force of the batteries used in the electric systems of automobiles is commonly 6 volts. This is very low and would not be sufficient to force much current through long wires, but as the distances in a car are short an electromotive force of 6 volts is sufficient, provided large wires are used. The danger from poor insulation is less with low voltage, for unless good contact is made in a short circuit little or no current will flow, and no damage will be done. In house-lighting the distances that the current must travel, both inside the house and on the way to it, are much greater. For this reason a higher electromotive force is used. Most residence-lighting circuits are operated at about 110 volts, though sometimes as low as 32 volts are used in farm-lighting plants.

Each piece of electrical apparatus must be used on a circuit carrying the voltage for which it is intended. If used on too high voltage, the apparatus will be ruined; if used on too low voltage, it will not operate. If a 6-volt automobile lamp were placed in a 110-volt circuit, the greater electromotive force would send so much current through it that the filament would be melted or vaporized, but a 3-volt circuit might not force enough current through to make the filament even red-hot; hence no light would be secured.

275. Some outstanding facts. Men sometimes speak of today as the "electrical age," because electricity is so important in modern life. This general statement is striking, but to know how to use electricity a good many facts must be kept in mind. Some of the things we have noted are that electricity operates through a connected or closed circuit of wire or other conducting

material; that when the resistance of a wire is great or when the wire is small the wire may become heated and may produce light; that in a suitable circuit including a lamp the light may be turned on or off by use of a switch; that any device for disconnecting and connecting the circuit may serve as a switch, but the knife and push-button switches are the most common; that heat is also produced by electricity, and this may be used in electric irons, toasters, etc. or may be lost; that when the circuit is greatly shortened, and a large amount of current thus flows through an easy path, great heat and possibly damage may be produced; that to prevent damage the wires should be kept well covered and fuses should be so arranged that they will disconnect the circuit when the current is too great; that lamps may be connected so as to operate separately (in parallel) or so that all or none will operate (in series); that electric current may be measured in amperes, by an instrument known as an ammeter; that there are several kinds of electric lamps, the best now in use being gas-filled lamps with tungsten wire; that the dry cell is a most important special device for producing electric current for many kinds of uses; that the electric pressure which causes the current to flow is known as electromotive force and is measured in volts. What other outstanding facts about electricity do you know?

CHAPTER XIX

POWER FROM ELECTRIC CURRENTS

276. Questions for discussion. 1. How is a compass constructed? 2. What kinds of materials are attracted by a magnet? 3. Do magnets lose their magnetism? 4. What kind of a magnet is used in an automobile ammeter? in a battery-testing ammeter? in a watt-hour meter? in a telephone ringer? 5. How can a magnet be made that will operate on the current from a dry-cell battery? 6. Who invented the electromagnet? 7. How are electric bells connected? 8. How does an annunciator work?

9. What are the necessary parts of an electric motor? 10. How is electricity used in operating street cars? 11. What is the difference between a direct-current motor and an alternating-current motor? 12. How is a motor started? 13. Why do most large motors have a "starting box"? 14. What are the advantages of electric motors? the disadvantages? 15. How are electric currents generated at the power plant? 16. Why are transformers used?

17. How is a "door opener" made? 18. How is a toy transformer made? 19. How is an automobile storage battery made? 20. What rules should be observed in the use of a storage battery? 21. What is the difference between an Edison storage cell and a lead storage cell? 22. What gases are set free when a storage battery is charged? 23. What is the cost of an automobile storage battery? 24. How long will an automobile storage battery last?

277. The ignition circuit. One of the important parts of the electric system of an automobile is the ignition apparatus. Without it the engine will not run. The ignition system produces a spark at the end of the spark plug in the cylinder. This spark ignites the gas at the proper time. How is this accomplished?

It might appear that the simple way would be to run a pair of wires direct from the battery to the spark plug. Try it, connecting one wire with the binding post, and the other with

the metal base of the plug. Do you get a spark between the points? Does the ammeter show that any current is flowing? Take a spark plug apart (fig. 135) and see whether there is a complete circuit through the plug. It will be found that the circuit is interrupted by a short gap between the points. The electromotive force (that is, the electric pressure or voltage in the current we are using) is not great enough to cause it to jump the gap in the spark plug. What is needed is a much stronger electromotive force. Examination of the ignition wiring will show that the wires run in such a way that several pieces of apparatus are inserted between the battery and the spark plug. One of these is called the coil. A study of the coil will help in finding how the necessary higher voltage is secured.

A coil such as is used on an automobile may be connected in the following way: The wire from the binding post of the spark plug should be connected with the terminal on the coil box to which the "high tension" wire is regularly connected. The wire from the base of the plug must be connected with the "ground" of the coil. Next touch the battery wires to the terminals marked "battery" on the coil. At the moment the battery is connected with the coil, a spark should jump across the gap between the points of the plug, and another should occur when the wires are removed from the terminals. The coil is the device that raises the voltage to the point where it will jump the gap. Since an ignition coil is commonly inclosed in a case, and the spaces are filled by pouring in a melted compound which hardens when cool, information regarding construction of the coil cannot be readily secured.

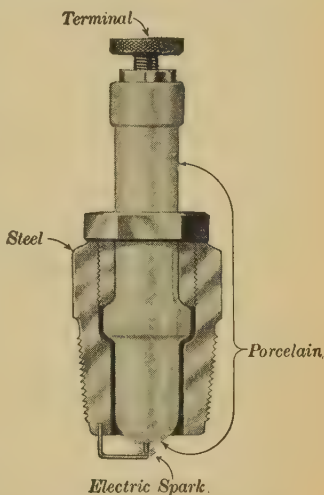


FIG. 135. An automobile spark plug

However, if an experimental laboratory coil is available, the construction of the coil may be studied. Such a coil really consists of two coils of wire. One is composed of a few turns of rather coarse wire, the other of many turns of very fine wire. The first-mentioned is known as the primary coil. It is connected with the battery circuit. The other is known as the secondary coil. It is usually placed outside of and surrounding the primary coil, but the wire in the secondary coil is in no way connected with the primary circuit. A bundle of iron wires or an iron rod will be found in the center of the primary coil.

Connect the spark plug with the terminals on the secondary coil and make contact with the primary terminals so that the current flows through the primary coil. A spark will jump as when an auto-ignition coil was used.

278. Vibrator coils. Most laboratory coils and some ignition coils are supplied with a vibrator which, when the battery is connected, vibrates continuously with a buzzing noise. If such a coil is used in the experiments suggested above, instead of a single spark when the battery is connected with the coil, there will be a series of them continuing as long as the primary current flows.

279. How the coil works. In experiments with a coil without a vibrator it will be noticed that a current flows in the secondary only at the moment when the battery circuit through the primary is being closed or opened. Once the circuit is closed and the current flowing steadily, no current can be detected in the secondary circuit. We conclude that in order to secure a spark we must have not only a primary and secondary coil and a source of current but also a means of interrupting the primary current at the moment it is desired to produce a spark at the spark plug. Many kinds of devices called current breakers are used for this purpose.

280. The high-tension current. The current produced by the secondary coil has a high electromotive force, usually ten thousand volts or more. It is therefore often called a high-tension current. Exactly how great the electromotive force shall be

depends to a great degree upon the number of turns of wire in the secondary coil. There may be several thousand turns.

The primary wires, carrying a current of only 6 volts, may be handled without danger of shock, as that voltage will not send an appreciable current through the human body. A 110-volt current may be dangerous, and in any case is capable of giving an unpleasant shock. The circuit over the high-tension wires of an automobile to the spark plugs may carry a current at such exceedingly high voltage that it will overcome the resistance of the human body and produce a dangerous shock. High-tension wires should be very well insulated, and only wires of special construction should be used for this purpose. One should be very careful not to bring any part of the body close to the high-tension wires or the spark plugs when the coil is in operation.

281. Danger of electrical injuries. A means of measuring resistance to currents is necessary. The unit of resistance is called the ohm. The resistance of 160 feet of No. 18 copper wire is approximately one ohm. An electromotive force of one volt will send one ampere of current through a resistance of one ohm. Expressed mathematically:

$$\text{Current} = \frac{\text{electromotive force}}{\text{resistance}}$$

or

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}}.$$

The resistance of the human body is from 1000 ohms to 10,000 ohms or more, depending largely upon the condition of the skin. If we suppose the resistance to be as low as 1500 ohms, a single dry cell (1.5 volts) ought to force through the body one thousandth of an ampere. With a very delicate measuring instrument this current can be detected, but it cannot be felt. An electromotive force of 10,000 volts might be expected to send seven amperes through the same resistance.

A current of about ten amperes is used in the electrocution of criminals, and as low an amount as one-tenth ampere may be

dangerous under certain conditions. It is therefore clear that it is necessary to be very careful regarding wires carrying high-tension currents.

Workmen regard from 400 to 600 volts as sufficiently high pressure to force enough current through the body to be fatal. Cases are recorded in which the 110-volt lighting circuit proved fatal. The main wires distributing current for city lighting commonly carry current at 2200 volts, but this high pressure is lowered to 110 volts on the wires leading into the houses. Street-car motors commonly operate at 600 volts. The lines used for long-distance transmission of electricity operate at pressures as high as 10,000 volts or even 100,000 volts or more.

282. Coils in electrical apparatus. Anyone who examines various kinds of electrical appliances is sure to find that very many of them, like the ignition apparatus of automobiles, contain coils of wire. Coils are found in doorbells, toy motors, magnetos, electric fans, sewing-machine motors, telephones, telegraph instruments, and in many other appliances. In fact, coils are essential parts of most electrical devices excepting those intended for lighting or heating, such as lamp bulbs and electric irons. A study of these coils of wire may then make it possible to understand the working of ignition coils, motors, and other devices.

283. Magnetic effects of coils. A small coil for experimental use may be made by winding some insulated wire around an iron spike three or four inches long or a large nail. The current from a single dry cell should be passed through the coil, but care should be taken that the current is not allowed to heat the wires greatly.

When the current is flowing through such a coil it will be found that the coil and its iron core act as a magnet. It may be used to pick up small iron objects, such as tacks, but as soon as the current is interrupted, it ceases to be magnetic, and the objects it is holding are dropped. If the iron core is removed while the current is flowing, the magnetic effects remain, but are weaker.

The effects of such a coil are similar to the effects of a common steel magnet, or permanent magnet. A steel bar magnet may therefore be used in place of a coil in the first study of magnetism. Afterward electromagnets (fig. 136) and their relation to electric currents will be further studied.

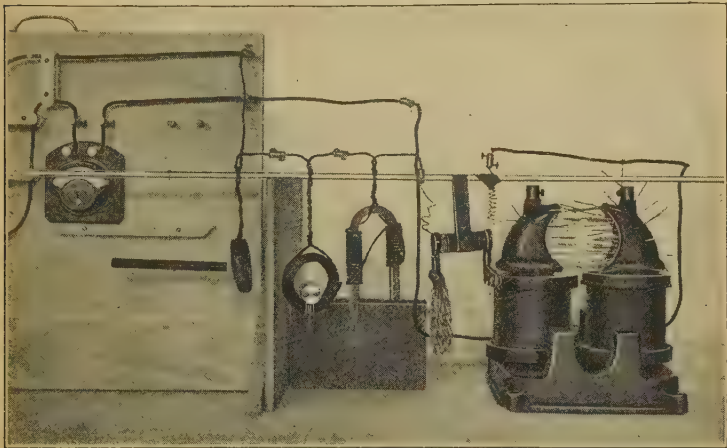


FIG. 136. Demonstration materials for studying electromagnets

The coils are connected in series and carry a current of one ampere. From left to right: bar magnet; three coils of wire wound upon iron cores, the whole serving as magnets (the U-core when wound becomes a relatively strong magnet); the electromagnet of a small motor; the electromagnet of a larger motor or dynamo. The adhering nails indicate the region of magnetic action, or lines of force

284. Permanent magnets and their uses. If a bar magnet is covered with small nails or iron filings and carefully lifted, most of the adhering metal (fig. 137) will usually, though not always, be near the ends of the magnet. The parts in which the attraction is the strongest are called the magnetic poles.

If a bar magnet is suspended horizontally by a piece of thread at some distance from other magnets and iron, and left undisturbed, it will take a position pointing approximately north and south. For convenience we call the north end the

north pole (*N*), and the south end the south pole (*S*). It can easily be shown that like poles of different magnets (two *N* poles or two *S* poles) repel one another and that two unlike poles attract one another.

A compass can be made by magnetizing a steel needle, a safety-razor blade, a small file, or a piece of watch spring. When placed on a floating cork or balanced on a pivot the magnet takes a north-and-south direction. This action of the compass



FIG. 137. Demonstration materials for studying permanent magnets

The materials suspended from the rod are three bar magnets to which nails and cobalt and nickel cubes adhere; a horizontal bar magnet with nails adhering at both ends, the whole acting as a compass; two U-magnets with nails, one holding the nails though separated from them by cardboard; a U-magnet holding a nail and piece of wire; two types of compasses

is due to the influence of the earth, which acts as though it were a magnet, having a south magnetic pole near the geographical north pole of the earth, and a north magnetic pole near the south pole. The compass needle does not point north and south on all parts of the earth, because the magnetic poles do not coincide exactly with the geographical poles. The compass is used by hunters, sailors, and explorers to determine the directions.

Artificial magnets, such as described above, are made by rubbing steel with a loadstone (a mineral with permanent

magnetic quality) or by the use of an electric current. Magnetic tack hammers, telephone magnets, magneto magnets, and toy horseshoe magnets are permanent magnets; the magnet of an electric bell, however, is a temporary magnet, the magnetism of which depends upon the presence of an electric current in a coil of wire about the iron. Permanent magnets gradually lose some of their magnetism and may be damaged by contact with other magnets, by heating, by mechanical shock (pounding, falling to the floor, etc.), by failure to provide iron keepers for the ends, and by placing the keeper in position abruptly.

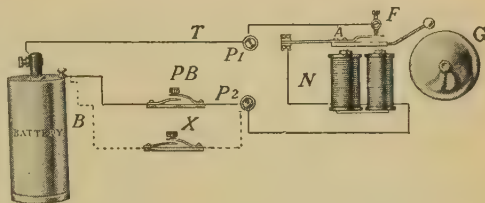


FIG. 138. Essentials for an electric bell

B, dry cell; *G*, bell; *PB* and *X*, push buttons at different places, each connecting with the bell ringer, *A*, by means of its own circuit; *P*₁ and *P*₂, binding posts; *N*, magnets

285. Uses of small electromagnets. Electromagnets made by winding insulated wire about an iron core were first made in 1828 by Joseph Henry of Albany, New York. Many thousands of magnets of this type are now manufactured annually. The range of size is from the tiny coils in a telephone receiver to the giant lifting magnet which handles several tons of iron or steel at one lift.

The electric bell (fig. 138) consists of two coils of wire forming an electromagnet of the U-type. When the current flows through these coils a piece of metal which is attached to the clapper is suddenly drawn over, thus ringing the bell. The exact operation of any bell and its wiring circuits should be learned by examination and by the construction of a system of electric bells.

Other examples of electromagnets may be found in electric toys, clocks, door openers, annunciators, telephones, telegraph instruments, arc lamps, motors, automobiles, and street cars.

286. Uses of large electromagnets. Electromagnets of great strength are required in electric motors and generators. The most powerful machines have very large coils, which are usually made of thick copper rods or bars. A single electromagnet of a huge dynamo may have as much as two hundred pounds of copper in the coil, and the dynamo may contain thirty-six coils.

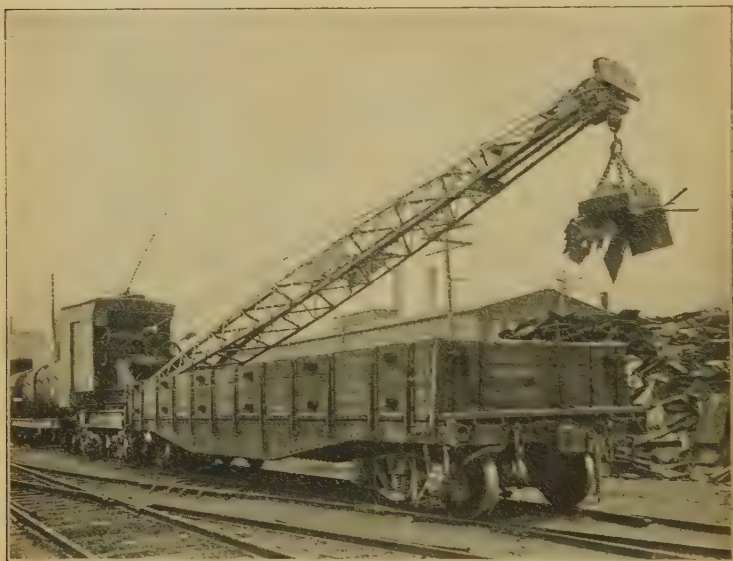


FIG. 139. The lifting electromagnet

Used in lifting heavy iron and steel such as pig iron and steel rails. A magnet thirty-four inches in diameter may be made to lift four tons of solid iron

An example of the lifting magnet is shown in figure 139. This type is very commonly used in steel mills where it is employed in handling pig iron and scrap iron. It is said that two men can use two similar magnets sixty-two inches in diameter to unload as much as four million pounds of pig iron in ten and one-half hours. Electric engines, street cars, subway trains, and the electric generators for power plants could not operate without powerful electromagnets.

287. The region about a magnet. When a horseshoe magnet is dipped in iron filings or small nails (fig. 137) and then removed, the metal usually forms a loop from one pole to the other. When a glass plate or a sheet of paper is placed over the horseshoe magnet, and fine iron filings are sprinkled evenly over the plate, if it is tapped slightly the filings arrange themselves in definite lines running from the north pole to the south pole of the magnet. Each small piece of iron becomes a tiny magnet and joins its neighbor, forming a connected line of filings. Nails or tacks are affected in the same way, but since they are larger, the line formed is irregular.

These lines will always be found in some form near magnets. For convenience they are called lines of force. In some regions the lines will be numerous; in others only a few will be found. Permanent maps of the lines of force can be made by using blue-print paper or paper covered with paraffin. In the latter case the paper must be warmed slightly to "set" the filings. It will be found most interesting to prepare such maps of the lines of force. Scientists, engineers, and electricians find that the pictures of lines of force assist in the understanding of motors, dynamos, electromagnets, and electrical instruments.

288. Effect of coils upon one another. In connection with the study of ignition apparatus in automobiles it was noted that although the primary and secondary wires of the ignition coil are not connected, yet when the battery is connected with the primary wires a current flows in the secondary wires. How can the current in the primary coil cause a current to flow in the secondary coil when the latter is not connected with the battery?

To show that there is no connection between the two coils, use two simple homemade coils of wire instead of the ignition or laboratory coil. Wrap about fifty feet of common insulated bell wire into a coil which is about six inches in diameter. Lay the coil on the table and arrange so that a single dry cell can be connected to the ends of the wire. Make another similar coil and support it about an inch above the first, and parallel to it. As a means of detecting current in this second coil, con-

nect the ends of its wire to a galvanometer. The galvanometer is an instrument somewhat similar to the ammeter, but much more sensitive. When the dry cell is connected to the first coil so as to send a current through it, the galvanometer will show that a current flows through the second coil at the moment when the circuit is made. It flows again when the circuit is broken. This occurs although the coils are plainly separated by the distance of an inch. If they are brought closer together and the experiment repeated, the effect upon the secondary is greater; if they are separated more widely, the effect is less. Find out how far the secondary may be removed from the primary and the galvanometer still be affected by the "make and break" in the primary circuit.

An explanation of the influence of the primary on the secondary coil is suggested by the experiments of the preceding sections. A coil acts as a magnet, and therefore the space around a coil, when carrying a current, is filled with lines of force such as were mapped about permanent magnets (Sect. 287). These lines of force from the primary coil will pass through the secondary coil if it is near the primary coil. It is by means of its magnetism, therefore, that the primary coil affects the secondary. Since the current in the secondary flows only at the moment of making or breaking the circuit, it appears that the flow of current in the secondary is produced by the increase of the lines of force (when the primary becomes a magnet) and by the decrease in the lines of force (when the primary ceases to be a magnet).

To test further whether the current in the secondary is caused by the increase or decrease in the lines of magnetic force passing through it, try various methods of varying the number of lines of force through a coil. This may be done by making and breaking the circuit in the electromagnet, by moving the electromagnet away from the coil or toward it, by moving the coil, by moving a permanent magnet to and from the coil, or by rotating the coil near a magnet. Try as many of these as possible as a means of verifying the correctness of the conclusion.

If some of the above experiments are repeated and particular attention is given to the movements of the needle of the galvanometer, it will be seen that when the lines of force are increased the needle moves to one side, but when they are decreased it moves to the other side. This is because the current flows first in one direction and then in the other. Such a current is called an alternating current. The current in a vibrator coil alternates (changes direction) each time the current is made or broken by the vibrator.

289. Transformers. References have been made at several places to the practice of changing currents from high voltage to low or from low to high. The question may arise as to how this can be done. The coil in the ignition system of an automobile is for the purpose of transforming a low voltage into a high voltage. Such coils have a primary of relatively few turns of wire and a secondary of many turns. If one is constructed with the primary of many turns and the secondary with few, the voltage is reduced. Special devices for raising or lowering voltage are called "step-up" and "step-down" transformers.

With the coils used and discussed up to this time it was necessary to provide some kind of current interrupter in order that the magnetic field might increase or decrease. If an alternating current is used in the primary, the magnetic field will increase in strength when the current flows in one direction, decrease to zero as the current reverses, and again increase when the current flows in the opposite direction. At each reversal of current the magnetic poles will also be reversed. Because of this natural change in the magnetic field no vibrator or current breaker is needed.

The common bell-ringing transformers and toy transformers now so commonly used are step-down transformers, reducing the voltage of the alternating house current from 110 volts to from 1 to 30 volts. Similar but larger transformers reduce the main-line current (2200 volts) to 110 volts for safe use in the house.

290. Sources of current. In all the experiments up to this point the electricity used has been obtained from dry cells or

storage batteries, and no attention has been paid to the source of current. While both dry cells and storage batteries are used on automobiles, the usual first source of current is some sort of electric generator which is operated by an engine or by water power. Similarly, the source of the current for the house lighting and power is a large generator (fig. 140) operated by a steam or gasoline engine or by water power.

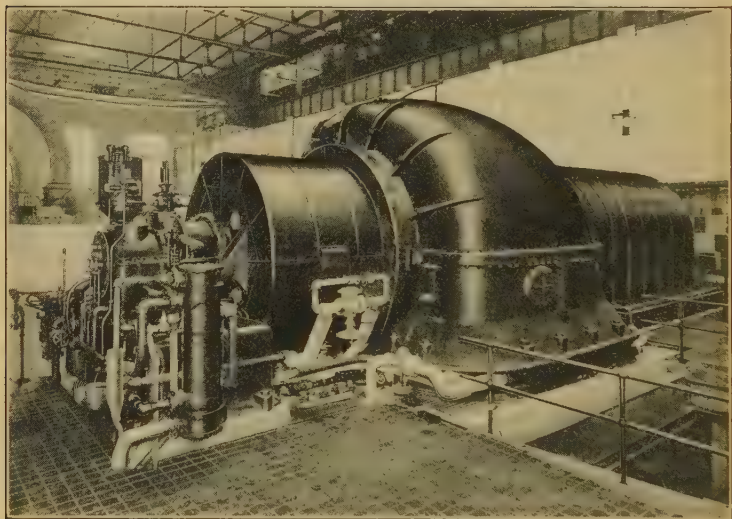


FIG. 140. A giant generator of electricity

This generator is driven by water power

291. A magneto. One type of current-producing apparatus that may often be found on an automobile is called a magneto. By carefully examining a magneto or by taking an old one apart, it will be found that the essential parts are (1) one or more U-shaped magnets; (2) a coil of wire wound on an iron core and arranged to rotate between the poles of the magnets; (3) some device, such as metal or carbon brushes, to make connection from the outside circuit to the ends of the wire in the rotating coil.

The coil of wire rotating in a magnetic field suggests that the current is produced by changes in the lines of force through the coil (Sect. 287). This is true. The galvanometer will show it to be an alternating current.

Magnetos are used to furnish current for ignition, since they can be constructed to furnish current at high voltage, and no ignition coil need be used. Magnetos are used also for "ringing up" in some kinds of telephones (fig. 141).

292. Dynamos. Current for other purposes than ignition, and sometimes for ignition also, is usually supplied by a different type of generator. If one of these is examined, it will be found that it has an electromagnet instead of a permanent magnet. The electromagnet is magnetized by current from the rotating coil. That is, the rotating coil (armature) and the coil on the magnet (field coil) are connected so that any current flowing through the circuit flows through both. It may be difficult to see how the generation of current begins, since operation depends upon electromagnetism. The explanation is that a little magnetism remains in the iron core of the field magnet, and this is sufficient to start generation. Such an apparatus for producing current is commonly called simply a generator, but in a larger power plant it is known as a dynamo.

293. The commutator. The armature of the dynamo, like that of the magneto, produces alternating current, but for many purposes it is desirable to have direct current, as for charging a storage battery. By means of the commutator the alternating current is changed to direct current.

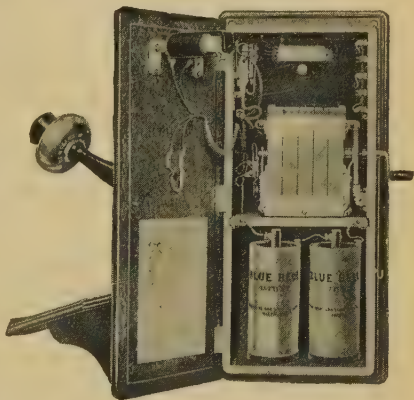


FIG. 141. The electromagnets and dry cells of a telephone bell ringer

A simple form of generator and commutator consists of two pieces of brass making an almost complete ring about the axle of the armature. The ends of the coil wire are soldered to the pieces of brass (commutator segments), and the brushes are so placed that at the moment when the current reverses in the armature the commutator segments pass from one brush to the other. Thus the connections to the outside circuit are reversed at the time when the current in the armature is reversed. This results in a current flowing always in one direction in the circuit outside the armature. Test it with a galvanometer and small generator.

While a simple generator may be constructed with only two poles on the armature, a practical generator has an armature so wound that there are many poles. There must be as many commutator segments as there are poles.

The direct-current power plant is used chiefly where the energy is not transferred to a great distance, as in rural communities, villages, homes, and stores, and often in cities for hotels, schools, and factories. The rural plant usually consists of a small direct-current generator having a capacity of about 1000 watts at 32 to 40 volts, a storage battery consisting of from 16 to 20 cells connected in series, a switchboard for the instruments, fuses, etc., and a gasoline engine to drive the generator. The larger direct-current generators used in factories and sometimes for the central power stations in small towns operate at from 250 to 300 volts or more. The current is obtained direct from the generator, usually by means of large copper cables.

294. Use of direct and alternating currents. A direct-current dynamo is always constructed to produce current of relatively low voltage, since a high-voltage current would jump across the spaces between commutator segments. This low-voltage current requires large conductors in order that the resistance and loss of energy by heating may not be too great. The expense of the large conductors is one of the disadvantages of the direct-current system. When large amounts of energy are to be

transferred over long distances, alternating-current generators are always used. They do not require commutators.

In the alternating-current system a generator consisting of a huge armature, driven by steam, gas, or water power, rotates in the magnetic field produced by electromagnets. The voltage produced by this dynamo is raised to a higher voltage by means

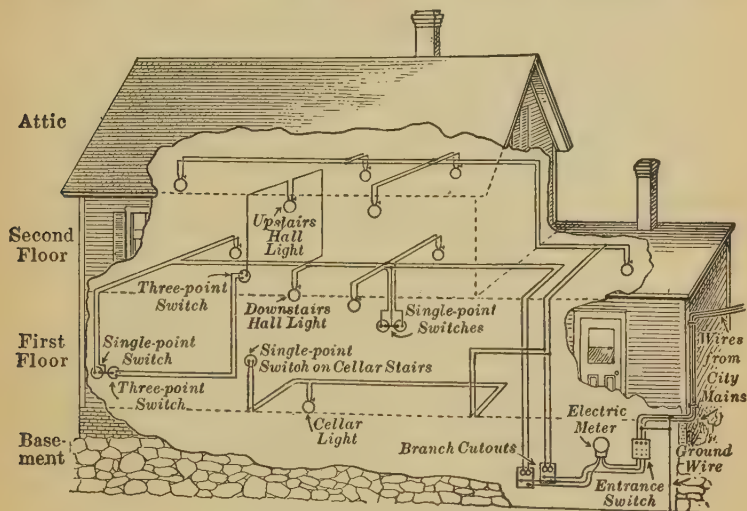


FIG. 142. How electricity is distributed through the house

Note the entrance conduit, the cut-out switch, the meter, and the courses followed by the distributing wires

of "step-up" transformers. The energy may be transmitted several miles with small loss, and then by means of "step-down" transformers it is made available for use. Smaller distributing transformers, such as are in most common use, receive the current at 1100 or 2200 volts and reduce it to 110 or 220 volts, which is a safe voltage for community use.

Wires from the low-voltage coils of the distributing transformers are brought to the basement of the residence, where suitable fuses and switches are installed. The watt-hour meter

is then inserted in the circuit, and the electricity is finally available in the rooms of the residence, as shown in figure 142.

295. Electric meters and meter reading. Since the current used in most homes, stores, and shops is supplied by a central power station, it is necessary to have some means of measuring the amount of energy consumed. The watt-hour meter, commonly called the electric meter, has been devised for this purpose. Although this instrument may appear to be a rather

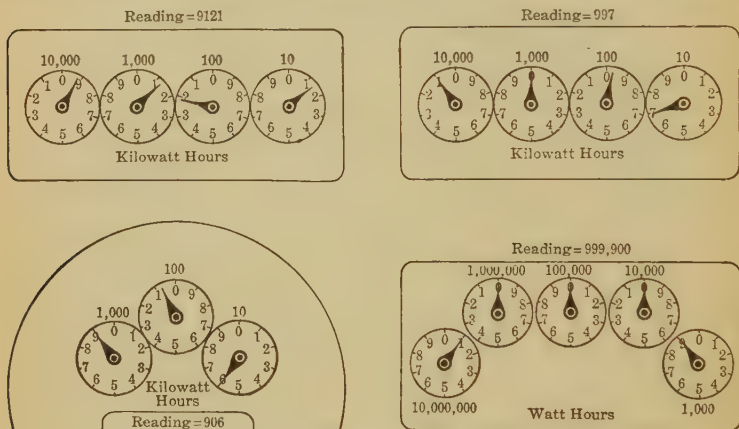


FIG. 143. Different types of watt-hour meter dials

To read the dials of the upper left-hand meter, begin with the right-hand pointer. The last figure passed by the pointer is 1; on the second dial, 2; on the third dial, 1; on the fourth dial, 9. Therefore the reading is 9121. Read the other meters, the dials of which are shown

complicated piece of apparatus, it is really a very small motor so connected that it is run by the current entering the house.

The motor in the watt-hour meter turns a series of wheels with pointers which indicate the amount of electric energy used somewhat as a speedometer indicates the number of miles traveled.

While the watt is the standard unit of electric power, it is a very small unit, and therefore in practice the kilowatt (1000 watts) is used. Meters are graduated to read in kilowatt-hours.

In figure 143 the dials for an ordinary watt-hour meter are

shown. In the meters in most common use there are figures above or below each dial to indicate the value of a complete rotation of the pointer on that dial. If there are ten divisions on the dial, each division is one tenth of the value of the number near the dial. Some of the pointers rotate clockwise and some counterclockwise, and the direction must be noted in each case. One revolution of the pointer on any right-hand dial is equal in value to one tenth of a revolution on the dial next to it on the

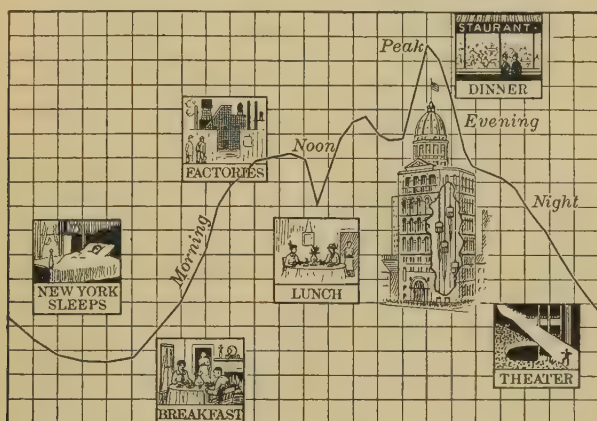


FIG. 144. Use of electricity at different times of day

The diagram represents a typical day's demands for electricity in New York City. Redrawn from *The Electrical Experimenter*

left. Sometimes a multiplying number is given, in which case the actual reading must be so multiplied in order to determine the correct values. Finally, the reading last made must be obtained and deducted from the present reading in order to show the correct amount of energy used since the last reading. The following example will show how the cost is computed:

Reading (present month)	= 9121 kilowatt hours
Reading (last month)	= 9101 kilowatt hours
Difference	= <u>20</u> kilowatt hours

Twenty kilowatt hours at 10 cents per kilowatt hour = \$2.
The bill for the month is \$2.

296. Operating cost of electric devices. As a source of heat and light, electricity is more expensive than gas, but there are compensations in the form of efficiency, adaptability, and cleanliness. The number of kilowatts used in New York City during a typical day and night is shown in figure 144. In the following list of common devices for the use of electricity there are also given the number of watts and amperes consumed per hour and the approximate cost per hour for each device.

COST OF OPERATING HEATING DEVICES

(Computed on a cost basis of ten cents per kilowatt hour)

DOMESTIC DEVICES

DEVICE	AMPERES TAKEN AT 110 VOLTS	WATTS CONSUMED	COST IN CENTS PER HOUR
Mazda B lamp, vacuum type, 47 candle power	.54	60	\$0.006
Mazda C lamp, gas filled, 1430 candle power	9.00	1000	\$0.100
Radiant toaster	5.45	600	\$0.060
Chafing dish	5.45	600	\$0.060
Disk stove	5.45	600	\$0.060
6-pound smoothing iron	5.00	550	\$0.055
8-inch fan (full speed)	.22	25	\$0.002
Sewing-machine motor	.50	55	\$0.005
Washing-machine motor	1.82	200	\$0.020
Heating pad	.20-40	22-44	\$0.005
Radiant grill	5.45	600	\$0.060
Ranges (2 to 4 people)	9.01-40.90	1000-4500	\$0.100-\$0.450

COMMERCIAL DEVICES

DEVICE	AMPERES TAKEN AT 110 VOLTS	WATTS CONSUMED	COST IN CENTS PER HOUR
Glue pots	1.0-8.0	110-880	\$0.011-\$0.088
Instrument sterilizers	3.2-4.5	350-500	\$0.035-\$0.050
Sealing-wax pots, 5-1.5 pt. . . .	1.6-2.7	175-300	\$0.017-\$0.030
Soldering irons, various sizes . .	.9-4.1	110-450	\$0.010-\$0.045
Vulcanizers for automobile tires .	.9-4.1	110-450	\$0.010-\$0.045

297. Motors. Examination of a small motor, such as a toy motor or the starting motor of a car, will show that it is so similar to a generator that it is difficult to tell them apart. In fact almost any direct-current motor will produce current if the

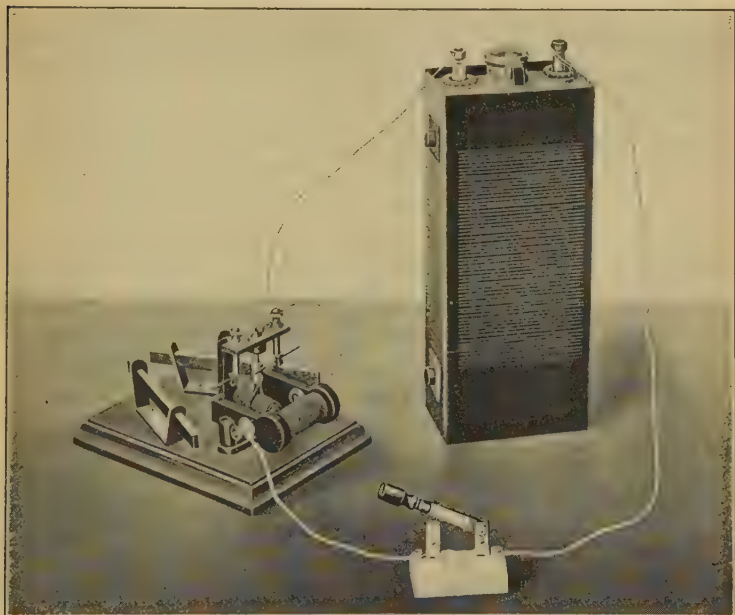


FIG. 145. A small demonstration motor

This motor is operated by an Edison storage cell

armature is rotated, and many generators can be used as motors. In some automobiles the starting motor is also the generator.

Motors are constructed to operate on either direct or alternating current. The direct-current motor is more readily understood, and it alone will be described here. The operation of a simple direct-current motor may be studied from an experiment such as is illustrated in figure 145. The electromagnet can be removed so that the bar magnets can be brought into place on either side of the vertical axle. The bar magnets then

furnish the magnetic field. A coil of wire mounted on an iron core is placed on the central shaft, which can be rotated. The ends of the coil are connected to a metal cylinder standing just above the coil. When the terminals of a single dry cell are attached, the current can pass through the metal brushes to the coil. When the switch is closed, the coil spins quite rapidly. The motor fails to operate, however, when two *N* poles or two *S* poles are used near the rotating coil. Why? The necessary parts of a direct-current motor are a suitable magnetic field, a coil for rotation (usually called the armature), and a device (usually called the commutator) to send the current into the armature at the proper instant and in the correct direction.

298. Different kinds of motors. Permanent magnets are not adapted for use in motors. A modification must be made in order that the magnetic field may be furnished by a stronger electromagnet, as is done in all practical motors. In figure 145 the bar magnets have been swung outward from the armature. A coil of wire wound upon a suitable iron frame is placed near the armature. The motor may now be operated, first, by using a different source of current for the armature and electromagnetic field; second, by connecting the armature and field (the terminals of the coil) in series with a source of current; third, by arranging the armature and field circuit in parallel with a common source of current.

The first method is not suitable for practical motors; the second illustrates the series motor, which is used in electric vehicles and at times on street cars; and the third represents the so-called "shunt" motor, which has extensive use. An additional type of direct-current motor, called the compound motor, is a combination of the series and the shunt motor. In addition to the direct-current motors there are several different types of machines that are designed to operate upon an alternating-current circuit.

299. The starting motor. The starting motor of an automobile is a direct-current motor. It takes current from the storage battery. Because it has a very heavy task to perform in turning

the engine, it uses a current of from 100 amperes to 200 amperes during the short time that it is in operation. Because of this large current demand, the wires leading to the starter must be very large or they will be overheated by the current.

As the generator usually delivers not more than 8 or 10 amperes of current, it is seen that the starter may take from the battery in one minute as much current as the generator sends into the battery in fifteen or twenty minutes.

300. Domestic and commercial uses of motors. Electricity provides the most convenient means of transmitting and using energy. The electric motor affords perfect control, reliability of operation, range of distribution, cleanliness, and less danger of accidents than other sources of energy. Motors are used in the home to operate washing-machines, vacuum cleaners, meat choppers, ice machines, fans, elevators, pumps, ice-cream freezers, and many other appliances.

There is almost no limit to the industrial uses of motors. Electric vehicles, printing presses, lathes, cranes, dental appliances, air compressors, coal cutters, band saws, shoemaking machinery, tool grinders, automobile and farm machinery, and many other applications may be given as illustrations.

301. The use of storage batteries. It is quite common in automobiles to use lights or other electric appliances when the engine is not running. Although the generator is not operating, it is evident that some source of electricity exists in the car. Indeed, the starting motor always operates under these conditions. This is made possible by the storage battery (fig. 146). What is a storage battery?

A simple experimental lead storage cell may be constructed in the following manner: Into a glass jar or cell containing one liter of water one fifth of a liter of sulphuric acid is slowly poured. Two lead plates with connecting wires are placed in the solution on opposite sides of the cell (fig. 146). If the wires from the two lead plates are attached to binding posts which are connected to a battery of dry cells, and the switch is closed, an ammeter will show that a current is passing through the cir-

cuit, and bubbles will be seen near the lead plates. This action should be allowed to continue for a minute or more, and then it may be interrupted by disconnecting the battery.

If the dry cells are now disconnected from the binding posts, and an electric bell is inserted in the circuit, the bell will ring. Since the two lead plates in the sulphuric acid would not ring

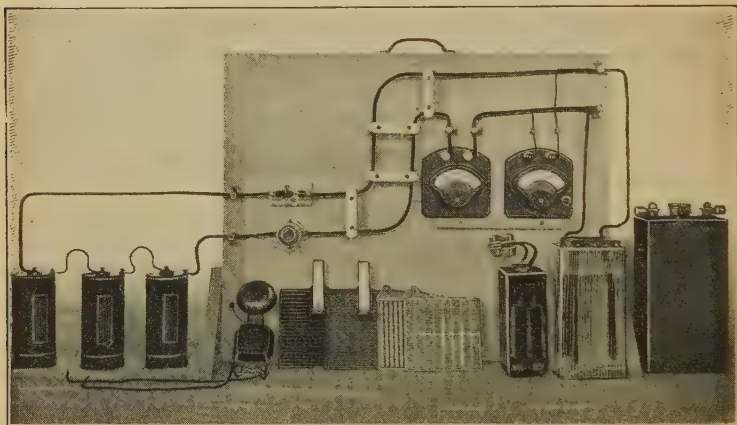


FIG. 146. Materials for studying the lead storage cell

The solution in the cell contains 1 liter of water into which $\frac{1}{2}$ liter of concentrated sulphuric acid has been slowly poured. From left to right the materials shown are three dry cells, an electric bell, two storage cell plates, two Edison cell plates, a commercial lead storage cell, a laboratory-made lead storage cell connected with wires, and an Edison cell

the bell originally, a change occurred while the current was passing through the acid solution. Examination will show that one of the plates is now coated with a brown deposit called lead peroxide, a compound of lead and the oxygen which was set free at the plate connected with the positive terminal of the battery.

As the current rings the electric bell the brown deposit may partially disappear, and the two lead plates soon reach such a condition that the bell fails to ring. The cell can be charged again, however, and the entire process repeated.

Electricity is not stored in this cell, however, in the same way that milk is kept in a bottle. As the current flows through the solution the surface of one of the lead plates is changed chemically into lead peroxide. This process is known as charging the battery. It produces the necessary conditions for any electric cell; that is, two unlike plates in a solution that will conduct the electric current. As the current is taken from the cell the lead peroxide disappears, thus discharging the cell. This simple device illustrates the principle of the lead storage cell. In the commercial battery two or more cells are used, the plates are closer together, are strongly supported, and differ in other details of construction.

302. The automobile storage battery. The automobile makes constant use of a storage battery. The battery is usually found in a heavily constructed box (fig. 146) in which two or more cells are connected in series. Electric current at voltages depending upon the number of simple cells in the battery may be obtained to operate the motor which starts the gas engine, or to light the lamps.

Storage batteries are quite expensive and require intelligent care, else they are soon ruined. Owing to their special construction a large current may be taken from them. Their voltage is high, they offer little resistance, and hence they can furnish larger currents. Some automobile-starting motors may require for an instant as much as 250 amperes or more. This is about five hundred times the current consumed by the 60-watt tungsten lamp. The owner of a storage battery should follow the instructions of the maker concerning its care. The rules given on page 274 will prove helpful.

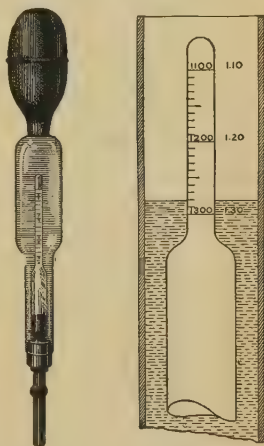


FIG. 147. Hydrometer for testing the acid in storage cells

The hydrometer syringe is so constructed that by its use the specific gravity (density) of the acid may be determined

Do not short-circuit the terminals of a storage battery. Do not use an ammeter to test the cells.

The battery should be kept free from dirt and foreign substances, both solid and liquid.

The battery must always be charged with direct current in the right direction.

Keep all connections clean and tight.

Do not bring a flame near the battery during or immediately after charging.

The acid should be kept at the proper height above the top of the plates.

Use only pure water, and handle it in nonmetallic vessels.

Do not add acid to the cells.

The battery should be charged at the proper amperage and for the proper length of time.

The condition of the battery is indicated by the specific gravity (density) of the solution, which is determined with a hydrometer syringe (fig. 147).

The acid of one make of battery has a specific gravity (density) of 1.28 to 1.3 when charged and of 1.1 to 1.15 when fully discharged. Other makes may differ.

Test the battery each week. If the specific gravity (density) of one cell continues much lower than the others, it may need the attention of a battery expert.

CHAPTER XX

ELECTRICITY IN COMMUNICATION

303. Questions for discussion. 1. How long have systems of telegraphing been in use? 2. How long has telephoning been in use? 3. What is the first telegraph message of which there is record? 4. In how many ways are electric communications used in your community? 5. What is the greatest distance over which telephone conversation may be conducted? 6. What is the greatest distance over which telegraphic communication may be conducted?

7. What is the longest existing cable line? 8. What is the cost of a ten-word cable message from London to your nearest telegraph station? 9. Why do cablegrams cost more than telegrams? 10. What is the greatest distance over which radio messages are transmitted? 11. What are the essential parts of a simple radio outfit? 12. What special adjustments or apparatus are required for one of the best radio outfits? 13. What is electricity?

304. Primitive methods of signaling. No doubt our ancestors of thousands of years ago had methods of communicating with each other and from village to village across the intervening space. Certainly most primitive and savage peoples of the present day have such means. The American Indians use smoke from small fires for conveying information to their friends, and the savages of Africa pass news from one village to another by means of drum beats. The ancient Greeks and Romans signaled at night by fires and in the daytime by means of their shields. None of these methods of communicating intelligence were sufficiently practical to be used to any great extent, though they were important in emergencies, as in time of war. The first widely successful means of communication at a distance was the magnetic telegraph, and it remains unsurpassed for many purposes.

305. The magnetic telegraph. Shortly after Joseph Henry devised the electromagnet, Samuel Morse began to try sending signals by means of an electric current, using an electromagnet as the receiving instrument. By 1843 he had constructed a successful telegraph line between Baltimore and Washington.

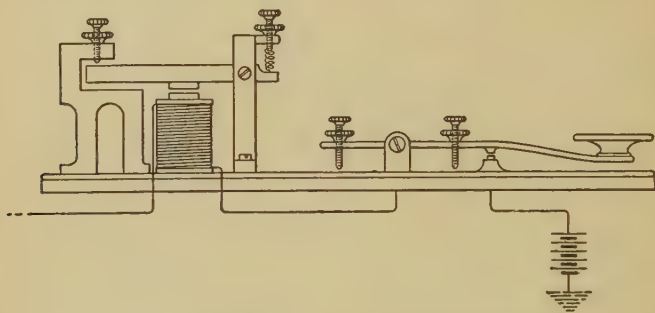


FIG. 148. Diagram of a telegraph key and sounder

A simple telegraph consists of sending key (fig. 148), receiving sounder, connecting wires, and a source of current. The key is essentially a switch. When the lever is depressed by the fingers, the two contact points are brought together, closing the circuit

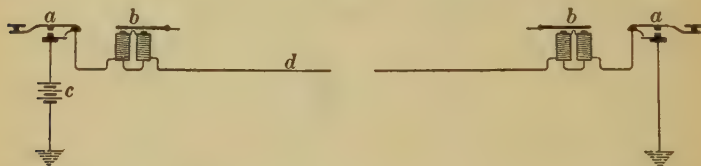


FIG. 149. Diagram of the apparatus at the two ends of a telegraph line

(figs. 148 and 149, *a*). When the lever is released, a spring separates the contacts, breaking the circuit. Thus a current flows through the circuit intermittently at the will of the operator.

The sounder consists of a pair of electromagnets and a movable piece of iron (figs. 149, *b*, and 148). If the key is closed at the sending station, the current flows, and the coils

of the sounder produce a magnetic field. The armature is attracted to the electromagnet, producing a sharp click. When the current is interrupted, a spring draws the armature away from the magnet; the armature bar strikes a metal stop, producing a second sound. There are thus produced at the receiving station a series of sounds corresponding with the movements of the key at the sending station.

An experimental telegraph line can readily be arranged in the classroom. If a set of telegraph instruments can be secured, they may be placed at opposite ends of the room and connected by wires, with a dry battery in the circuit. If the instruments are not at hand, they may be improvised. A piece of iron placed close to an electromagnet with a spring to draw it away when released will serve as a sounder, and an ordinary push button makes a serviceable sending key.

306. The Morse alphabet. In order that information may be conveyed through the telegraph it is necessary that the operators at the two ends shall be agreed on some system of signals, or code. Morse devised an alphabet consisting of combinations of long and short signals, commonly called dots and dashes. Two such codes are now in use, the American Morse and the Continental Morse. They are shown in figure 150, on page 278.

307. The telephone. It is much more difficult to transmit and reproduce speech than to transmit simple signals, because the sounds of speech are very complex. Human speech is so peculiarly associated with living vocal structure that we recognize people by their speech even though we cannot see them. The problem, therefore, of reproducing human speech from mechanical structures seemed quite impossible. Hence the even greater wonder of our day when from dead mechanical things we can recognize the yet living voice of a singer who himself has ceased to live. It was not until 1876, more than thirty years after the invention of the telegraph, that Alexander Graham Bell succeeded in making the first successful telephone. Before it is possible to understand the construction and working of the telephone it is necessary to know something of the nature of sound.

308. Sound and sound waves. Sounds are produced only by a vibrating body. Familiar examples of bodies which vibrate visibly while sounding are guitar and violin strings, piano wires, and tuning forks. In some cases the vibration is not sufficiently

LETTER	CONTINENTAL MORSE	AMERICAN MORSE	LETTER	CONTINENTAL MORSE	AMERICAN MORSE
A	· —	· —	T	—	—
B	— · · ·	— · · ·	U	· · —	· · —
C	— · — ·	· · ·	V	· · · —	· · · —
D	— · ·	— · ·	W	· — —	· — —
E	·	·	X	— · — —	· — · ·
F	· · — ·	· — ·	Y	— · — —	· · · ·
G	— — ·	— — ·	Z	— — · ·	· · · ·
H	· · · ·	· · · ·			
I	· ·	· ·	I	· — — — —	· — — — —
J	· — — —	— · · · ·	2	· · — — —	· · · · ·
K	— · —	— · —	3	· · · — —	· · · — ·
L	· — · ·	— —	4	· · · —	· · · · —
M	— —	— —	5	· · · · ·	— — — —
N	· — ·	— ·	6	— · · · ·	· · · · ·
O	— — —	· ·	7	— — · · ·	— — · ·
P	· — — ·	· · · · ·	8	— — — · ·	— · · · ·
Q	· — — —	· · — ·	9	— — — — ·	— · · — —
R	· — ·	· · ·	0	— — — — —	— — — — —
S	· · ·	· · ·			

FIG. 150. The American Morse and Continental Morse signal codes

great to be visible, but it exists. The vibration of sounding bodies causes disturbances in the air which travel outward in all directions as waves in the air, somewhat similar to the waves on the surface of a pond which travel away from a disturbance, as when a pebble is dropped into the water. The speed with which sound waves travel is about eleven hundred feet per second. When these air waves reach the ear similar vibrations are produced in the eardrum and transmitted to the nerves of hearing.

The pitch of sounds depends upon the rapidity of vibration of the sounding body and the resulting number of waves per

second. Sounding bodies with slow vibration give a low pitch, but if the rate is less than about 16 vibrations per second, the human ear does not hear it. Objects in rapid vibration give sounds of high pitch in proportion to the rapidity of vibration

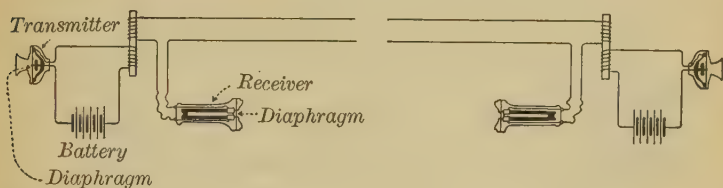


FIG. 151. Diagram of the sending and receiving ends of a telephone line

up to about 30,000 per second. The human ear is not able to hear sounds of a pitch higher than approximately 30,000 vibrations per second.

Sound waves striking an object are likely to set it into vibration, particularly if the object is tuned to the same rate of vibration as the sound. Thus, when a key of a piano is struck, it may set into vibration the corresponding string on a violin lying near.

309. The telephone transmitter.

The essential parts of a telephone line and the two sets of terminals are shown in figure 151. The transmitting and receiving instruments will be discussed in some detail, but

other parts will be postponed for possible later studies. At the bottom of the funnel-shaped opening of the transmitting instrument (fig. 152) of a common telephone there is a flat sheet of iron, or diaphragm. When one speaks into the telephone the sound waves strike this diaphragm and produce in it vibrations corresponding to those of the voice. In the common form of transmitter there is a box just back of the diaphragm and connected with it. This box is filled with grains of carbon and is

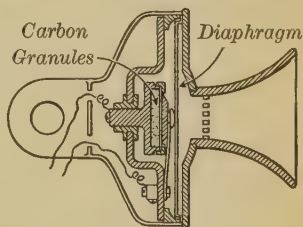


FIG. 152. Diagram of the telephone mouthpiece

connected with the telephone line in such fashion that the current which is flowing in the ~~line~~ passes through the carbon. As the diaphragm swings back and forth in its vibration it alternately exerts greater and less pressure on the carbon grains. The resistance which a quantity of carbon grains offers to the electric current varies when the pressure on them changes.

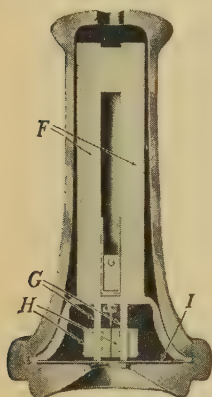


FIG. 153. A telephone receiver

Magnets at *G* surrounded by coils *H*, which are connected to the line wires, inclosed in the casing *F*, and the iron diaphragm *I*

When the diaphragm, in its vibration, moves toward the box it compresses the carbon, and the current passes easily; but when it moves outward the pressure is less and the current passes less easily. Thus the current is caused to vary in time to the vibrations of the diaphragm. Since the vibrations of the diaphragm reproduce those of the voice, the changes in the electric current flowing in the telephone wires will reproduce the vibrations of the voice.

The current from the transmitter is not commonly conducted directly to the receiver. Instead, it is passed through an induction coil by which it is changed into an alternating current and increased in voltage (Sect. 289). The higher voltage enables it to overcome the resistance of the long wire connecting distant stations, but the current retains the individual characteristics impressed upon it by the voice vibrations.

310. The receiver. The essential parts of the telephone receiver are a permanent magnet surrounded by a coil of very fine wire, an iron diaphragm, and a suitable case which contains these parts (fig. 153). The line wires from the transmitting station are connected to the coil, which acts as an electromagnet when current is passing through it (fig. 151). Since the current in this line is an alternating one, as we have just seen, it will produce an alternating magnetism; that is, the poles of the elec-

tromagnet will reverse in time with the alternations of the current. Since the permanent magnet does not change, the electromagnet will alternately oppose and reënforce the magnetism of the permanent magnet, thus producing a varying attraction for the diaphragm and causing it to vibrate correspondingly. The vibrating diaphragm gives out sound; and since the electric current in the telephone is controlled by the voice vibrations at the transmitter, the vibrations produced in the receiver diaphragm reproduce the sound of the voice.

311. Radio communication. No method of communication has aroused more interest than has wireless telegraphy and telephony, now commonly called radio communication. The thing that seems so very strange and that is the cause of much popular interest is the fact that no wires are used to connect the two communicating stations.

The passage of electrical influence across space without wires is not so strange to us as it seems at first thought. In the preceding pages we have had a number of examples of it. Thus, when a current is passed through a coil of wire it is able to produce a current in another coil at a short distance from it, or it will cause a compass needle to swing to a new position. This is an example of an electrical effect produced at a distance similar to wireless telegraphy.

312. Electromagnetic waves. No one who has read about radio communication or listened to conversation about it has failed to hear a great deal about waves. What are radio waves?

In order to understand about these waves the experiments with an induction coil should be recalled. In a preceding chapter it was learned that one coil affects another coil electrically through the magnetic field that it produces; that is, when a current passes through a coil it becomes an electromagnet, producing a magnetic field in the space about it. Indeed, not only a coil but even a single wire produces a magnetic field which can be detected at a considerable distance from it.

When a current is started through a wire this magnetic field spreads outward in all directions from the wire. If an alter-

nating current is passing in the wire, each successive alternation starts a magnetic disturbance which moves outward from the wire as a wave radiates from the source of disturbances. These are the electromagnetic waves or radio waves.

The speed with which radio waves travel is 186,000 miles, or 300,000,000 meters, per second. The alternating currents used in radio broadcasting have from 550,000 to 1,350,000 alternations per second. The distance from one wave to the next, or the wave length, is the distance a wave travels before the next wave starts from the wire, and may be secured by dividing the velocity of the waves by the number of alternations per second. Thus, if the number of alternations (frequency) is 660,000, the wave length is $\frac{300,000,000}{660,000}$, or about 454 meters.

313. Sending signals. The sending station is equipped with apparatus for the production of alternating current of the desired frequency by means of which it sends out electromagnetic waves as described above. The sending may be controlled by a key which interrupts the waves so that dots and dashes are transmitted in a fashion similar to wire telegraphy.

In radio telephony the waves are controlled not by a key but by the diaphragm of a telephone transmitter or some equivalent device. The waves are not wholly interrupted, but they are caused to vary in strength in accordance with the voice vibrations. Thus, if a sound whose waves are as represented in figure 154, *A*, is impressed upon a series of radio waves, the radio waves would be as shown in figure 154, *B*.

314. Receiving radio waves. It was learned in a preceding chapter that a change in the magnetic field about a wire tended to produce a current in that wire. The passage of an electromagnetic wave constitutes a change in the magnetic field and hence produces current in a suitable wire. Since the strength of the magnetic field increases and decreases with the passage of the waves, somewhat as the water rises and falls with the passage of a water wave, the current produced will be alternating with the same rate as the waves.

For the reception of radio waves special arrangements of wires are made, known as antennæ. The most common form

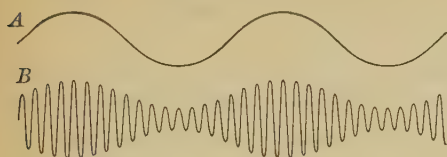


FIG. 154. Diagram of ordinary sound waves and of radio waves

of antenna consists of one or several wires stretched parallel to the ground at a considerable height, with a wire leading from one end of the antenna to the earth

(fig. 155, *a*). Passing waves induce an alternating current between the antenna and the earth. The rapidity and strength of the alternation will be controlled by the character of the waves, and the resultant current will therefore be like the current in the sending apparatus but very much weaker.

315. Getting sound waves from radio waves. It might appear that the only thing necessary in order to hear the signals picked up by an antenna would be to insert a telephone set (fig. 155, *b*) and listen. A little thought will show that the matter is not quite so simple. The frequency of the alternations is very great (660,000 per second, for example), while the ear cannot hear a higher frequency than about 30,000 per second. Moreover, the telephone receivers are not adapted to the high frequency.

316. The crystal receiver. The simplest form of apparatus used to make it possible to hear the high-frequency currents is the crystal receiver. A simplified diagram of such a set is shown in figure 156. The diagram shows that a "crystal" has been inserted in the circuit, in series with the telephones. Thus the current which passes through the tele-



FIG. 155. Parts of a radio set

a, antenna; *b*, inserted telephone; *c*, ground wire

phones must also pass through the crystal. It is a peculiarity of certain kinds of mineral crystals that when an electric circuit is completed through a wire (called a catwhisker) which lightly touches the surface of the crystal, the crystal allows a current to flow in one direction but prevents its flow in the opposite direction. If the crystal is placed in a circuit carrying an alternating



FIG. 156. Diagram of simplified radio circuit with crystal inserted

current, such as a radio circuit, only one half of each alternation can pass, and therefore the alternating current becomes a direct current. The effect upon the antenna current may be represented as in figure 157, where *C* represents the received waves, identical with the waves sent out (fig. 154), and *D* represents the waves of current as affected by the crystal. Since these waves are now all in the same direction they are, in fact, a direct current. All these small pulsations of current may be said to add together as in figure 157, *E*, and this current in the telephones produces vibration and sound like the original (fig. 154, *A*). Thus the telephone reproduces the original form and rate of vibration and therefore the original sounds. The principle of a crystal set, but not the details of construction, are shown in figure 156.

317. The vacuum tube. Crystal receiving sets are not difficult to make, but unfortunately they will not receive radio-telephone broadcasting satisfactorily at a greater distance than twenty-five miles from the broadcasting station. A much more efficient device than the crystal, but also much more complicated, is the vacuum tube. In many sets, especially those intended for long-distance reception, vacuum tubes are used. In order to understand how a vacuum tube works, it is necessary to know something more about the nature of electricity, and this will be taken up in the next section.

318. Nature of electricity. If a smooth rod of sealing wax is rubbed with a dry woolen cloth and then brought near to pieces of pith or shreds of tissue paper, these particles will be attracted to it. The same results can be secured by rubbing a glass rod with dry silk. The sealing wax and the glass are said to be electrified. If the glass rod is suspended horizontally by a string and electrified, and the electrified sealing wax is brought near it, it will be found that there is an attraction between them.

If a second glass rod, properly electrified, is brought near the first, a repulsion will be shown. It is seen that there are two kinds of electricity—that produced on the sealing wax and that produced on the glass rod. The

electricity produced on the sealing wax is called negative electricity, while that on the glass rod is positive. It is also clear that there is an attraction between positive and negative electricity, but positive repels positive, and negative repels negative.

It is believed that negative electricity consists of small particles called electrons. These electrons are exceedingly minute—much smaller than the atoms. They are usually a part of the atoms, but under certain conditions some of them may be removed from the atoms. There are also particles of positive electricity, called protons, but these remain in the atoms. When the sealing wax is negatively electrified by rubbing with the cloth, some of the electrons go from the cloth to the sealing wax. The sealing wax is negatively electrified because the electrons have accumulated on it, but the cloth is positively electrified because so many electrons have left it.

Electric currents are streams of particles of negative electricity, or electrons, moving along a conductor. The electrons are attracted by positive electricity and therefore move from a

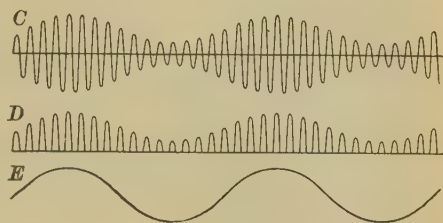


FIG. 157. The effect of the crystal upon the radio current

negatively electrified place to one that is positive, as from the negative to the positive pole of a battery.

319. How the vacuum tube operates. When a wire is heated in a vacuum, as in the common electric lamp, electrons are given off into the space around the wire. If another wire or piece of metal is inserted through the glass and made positive by being connected to the positive pole of a battery, electrons will be

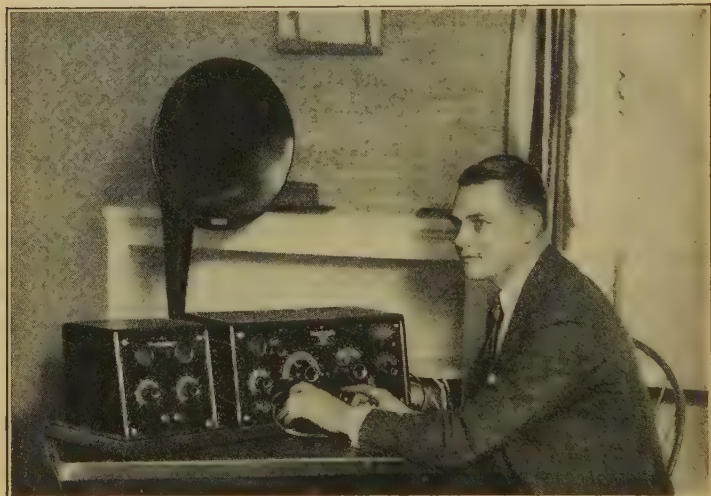


FIG. 158. A vacuum-tube receiving set

attracted to it. If the other pole of the battery is connected to the filament, a current will be set up across the space in the bulb and around the circuit (fig. 159).

In practical tubes this extra wire commonly ends inside the bulb in a small rectangular piece of metal called the plate.

Since the electrons are given off only by the filament, the resulting current, or plate current, can flow only in one direction—toward the plate. If we attempt to pass an alternating current between plate and filament, only that half of the alternation going from the filament to the plate can pass. Thus the vacuum tube will serve the same purpose as the crystal if inserted in a

radio circuit. Such a tube is called a two-electrode tube; in practical use it has been supplanted by the three-electrode tube.

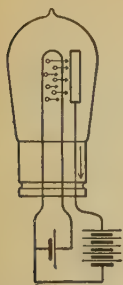


FIG. 159. A bulb for radio use

The three-electrode tube may be best understood in connection with its use in the receiving set. The accompanying diagram shows the arrangement of the simplest possible vacuum-tube receiving set, with the tuning devices omitted for the sake of simplicity (fig. 160).

In this arrangement the purpose of the battery marked *A* in figure 160 is to heat the filament. Battery *B*, figure 160, keeps the plate positive, and thus a current is produced across the space from the filament to the plate and on around the circuit through the phones (fig. 160, *a*) and back to the filament. Since this is a steady current no sound will be heard.

Between the filament and the plate there is inserted another terminal (fig. 160, *b*). It is usually constructed in the form of a latticework of wires and is called the grid. It is connected with the antenna. When an alternating current is set up in the antenna the grid becomes alternately positive and negative. When the grid is positive it assists the plate in attracting electrons from the filament, thus increasing the current in the plate circuit; when the grid becomes negative it opposes the flow of electrons to the plate, thus decreasing the plate current. Thus the plate current, which passes through the telephones, is caused to vary in agreement with the antenna current and the radio waves. Since the current can pass in only one direction, the plate current will be a direct current and will be able to affect the telephones. A diagram of the current in this case would

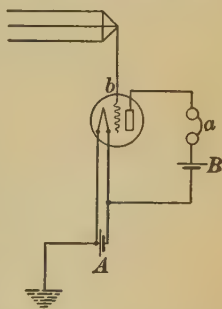


FIG. 160. Diagram of a simple vacuum tube receiver

be like the diagram of the current passing through a crystal (fig. 157), but with one difference. The size of the current flowing through the telephones in the vacuum-tube receiver is affected to a great extent by the battery (fig. 160, *B*), and hence much larger currents are passed through the telephones. This results in louder sounds. For this reason the vacuum tube can be used to receive over much greater distances than is true of crystal sets.

320. Tuning. In a preceding section it was shown that a violin string is easily set into vibration by a sound of the same pitch (or frequency) as the tone which the violin string would itself give out. In a similar manner the antenna and receiving set may easily take up the electrical vibration of a certain pitch or frequency. In order to receive at will messages sent out on different frequencies, it is necessary to have appliances which serve to tune the set. Those commonly used are condensers and coils, but the complete explanation of their proper use is too lengthy for insertion here. The instruments used in tuning are commonly assembled on a panel and inclosed within a cabinet (fig. 158). Further information upon tuning may be readily secured in special books upon radio communication.

PART IV. THE EARTH IN RELATION TO OTHER ASTRONOMICAL BODIES

CHAPTER XXI

THE SUN AND THE SEASONS

321. Questions for discussion. 1. Is your distance from the sun the same in the morning as at noon? 2. Would any difference in your distance from the sun at morning and at noon have any important effect upon the temperature? 3. How can you account for differences in temperature between morning and noon, and noon and evening? 4. Why is it not warm at the north pole during the season of long days in that region?

5. What differences are there in the length and intensity of shadows at noon, in the early morning, and in the late afternoon? How are these differences explained? 6. In southern Texas corn may sometimes be planted in February; in Oklahoma, in March or April; in Iowa, in April or May; in Minnesota, in June or early July. Why is there this seasonal progression in corn planting? 7. Why is it not possible to grow the same kinds of corn in all these regions?

8. The earth is so far from the sun (92,900,000 miles) that we cannot understand what the enormous distance really means. Can you devise a demonstration which will give a better sense of this distance? 9. The diameter of the sun is 866,000 miles. How many earths side by side would be required to extend directly through the sun?

322. Our relations to the heavenly bodies. In ancient times, when men had learned little about the heavenly bodies, but wondered much, it was commonly believed that the stars and other heavenly bodies exercised great influence over the affairs and destinies of men. Thus one was sometimes said to be born under a lucky star or an unlucky one. Before any impor-

tant undertaking was started the astrologers were consulted to learn whether the signs of the stars and planets were favorable.

As centuries have passed, men have ceased to have the same faith in the influence of the stars. The astronomers, who have studied the heavenly bodies with great care and have learned much about them, have found no reason to believe that they exercise any of the influences formerly attributed to them. Most people no longer pay any attention to these ancient superstitions, though a few survivals of the old belief may be found, such as the directions for planting crops in certain signs of the moon.

While there is no foundation for the various superstitions that have been mentioned, some of the heavenly bodies do have important effects upon the earth and its inhabitants, and all of them are objects of interest.

The sun is the most important body in its effect upon the earth, and its most important influence is as a source of energy, as discussed in Chapter XVI. The principal form which this energy takes is that of heat. All are familiar with the warming effect of the sun's rays.

323. How the air is warmed. It probably does not occur to most people that the presence of the earth's atmosphere has a great deal to do with its temperature. However, the air itself does not get much warmth directly from the sun's rays, even though the rays pass through it. The air is relatively transparent, and both heat and light pass through it with very little hindrance. This may be illustrated better by the more familiar case of the sun's rays passing through glass (fig. 161). If the glass of a window is perfectly clean and transparent, the sunshine will pass through it and warm the room within, but the glass is not much warmed; if it is covered with dust and other substances which hinder the passage of the sunshine, the window is somewhat warmed and the room is heated and lighted less. In the same way the transparent air gets little warmth from the sun's rays which are passing through it, excepting as the heat is absorbed by dust, clouds, and water vapor. When the earth has been warmed, the lower layer of air is warmed

by the earth. This air, being lighter, is replaced by cold air, the whole body of air thus becoming warmed more or less. The temperature of the air therefore depends principally upon the temperature of the area over which it is moving, whether this area is land or water.

When the sun is not shining directly upon a part of the earth, as at night or on a cloudy day, the earth's surface is continually losing

heat to the surrounding space and therefore becoming cooler.

That the heat which passes off from objects upon the earth

warms any transparent medium through which it passes much

more than do the sun's rays when they pass through such a

medium is well illustrated by a greenhouse. Here the rays

of the sun pass through the glass with little loss, but

the heat which is given off by the objects in the greenhouse, after they have been warmed by the sun, does not easily pass through the glass. The heat is therefore retained in the greenhouse.

In like manner the sun's rays pass through the air to the earth, but the heat given off by the warmed earth's surface does not easily pass out through the air. Instead, the lower layers of air are warmed by the earth. In a later section of this book it will be shown that some astronomical bodies, such as the moon, cannot have climates similar to that of the earth, because these bodies do not possess atmospheres.

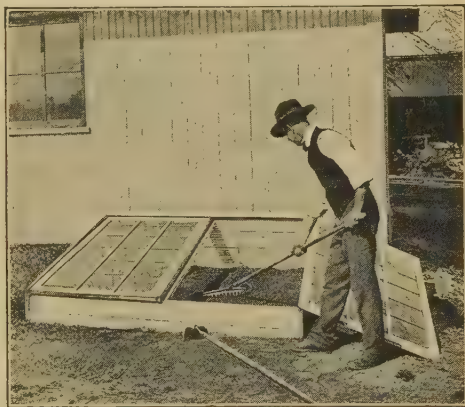


FIG. 161. Warm under glass, cold outside

This "cold frame" has long been used as a device for growing plants out of season and for protecting them against sudden changes in temperature. Early vegetables and seedlings for later planting are grown in these small greenhouses

324. Seasonal changes of temperature. The change in temperature that comes with the seasons is one of the most noticeable differences between the seasons. Why should there be such a difference? Why are not our homes warmed as well by the sun in winter as in summer?

Different answers are given to this question, and some of the answers are very thoughtless. It might be supposed that the sun is actually less hot in the winter than in the summer, but in that case the resulting cold would affect the whole earth, while all of us know that in tropical regions it is very plain that the sun's heat has not decreased. Besides, if its heat decreased enough to account for our winter, we should doubtless be able to notice a difference in its brightness. A second explanation, and one that is very commonly given by pupils, is that the sun is farther away from us in the winter. It is very clear that if the sun were farther away, this would account for the lower temperature; but in that case the whole earth would have winter at one time. Recall your study of geography and determine whether this is true. Moreover, if the sun were much farther away at one time than another, it would appear very different in size, but it does not appear smaller in winter than in summer.

It has been found possible to measure the distance of the earth from the sun very accurately. The average distance is 92,900,000 miles, and the difference between the greatest distance and the least distance is about 1,000,000 miles, or near $\frac{1}{93}$ of the whole distance. This is hardly enough to produce any marked effect, and curiously enough the time when the earth is closest to the sun is during our northern winter (fig. 162). Certainly anyone who remembers his geography would be very thoughtless to try to explain the seasons in this way.

A third suggestion for explaining the seasons may be found in the apparent direction of the sun. Everyone knows that in the summer the sun at midday is almost overhead, but that in winter it is far south, so that the sun's rays do not strike us from the same direction in the two seasons. In figure 162 a line

drawn from the sun to a point *a* in the northern hemisphere on June 22 will meet the surface at nearly a right angle, while a similar line drawn to the same point on December 22 would make a very acute angle with the surface. These two lines illustrate the difference in angle of the sun's rays in summer and winter, all of which should be familiar from your study of geography.

All apparent changes in the sun's position are due to the movement of the earth around the sun and to the inclination of

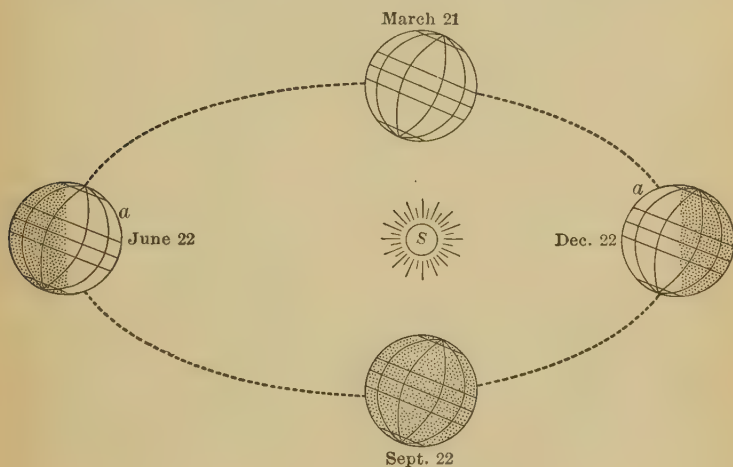


FIG. 162. The earth's orbit

Diagram showing the position of the earth with reference to the sun on four dates of the year

the earth's axis (fig. 162). We often say that the sun rises and sets, when we know that these appearances are due to the motion of the earth. In the same way we say that the sun is higher in the heavens in summer than in winter, meaning that we have changed our position so that the sun appears higher. It is also noted that daylight lasts longer in summer than in winter.

We therefore know that as the seasons change there is also a change in the apparent altitude of the sun and in the length of day and night. It is to these changes that the seasons are due.

325. Effect of changes in the sun's altitude. Why should it make a difference in the heat whether the sun is high up in the heavens or lower down near the horizon? It does make a difference, and we readily feel that the heat which is received at noon in the winter and at noon in the summer are not the same. The same thing is noted when the morning or evening effect of the sun is compared with the effect at noon (fig. 163).

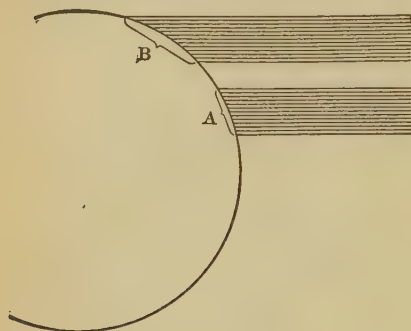


FIG. 163. Heating effects of the sun's rays

Diagram showing the difference in inclination of the earth's surface to the sun's rays. A sunbeam of the given size would cover more area at B than at A

The reason for this difference in the effect of the sun's rays is not difficult to understand if we make use of a simple experiment. Suppose in the morning, when the sun is not very high, a piece of paper with a large hole in it is held squarely facing the sun, and the spot of light which passes through the hole and appears on the floor or ground is measured. At noon the same

experiment may be performed, making certain that the card is the same distance from the spot and also squarely facing the sun. It will be seen that the spot of light observed in the morning experiment is larger; that is, in the morning, when the rays of the sun are more aslant than at noon, the rays of light and heat that come through the hole cover a larger space on the surface of the earth than at noon, when the rays are more nearly at right angles with the earth's surface. The amount of light and heat coming through the hole may be the same in both experiments, but in the morning they are distributed over more surface and are therefore less intense. If you spread your butter over a larger piece of bread, it will be spread thinner.

Of course the difference that has been discovered between morning and noon exists between winter and summer. Make a drawing showing exactly how large a space will be covered by a beam of sunlight one inch square if it comes to the earth at an angle of 65° ; of 18° . In which case would the earth's surface receive more heat to the square inch? How much more? Which corresponds to summer? to winter?

326. Length of day and night. In summer, when the sun is higher in the heavens, it is also visible more hours in the day. The difference between the longest day and the shortest is not the same at all places. It is least at the equator and greatest at the poles. At intermediate places the difference corresponds to the distance from the equator. In the central part of the United States (central from north to south) the longest daylight, in the latter part of June, is about fifteen hours, and the shortest, in the latter part of December, is about nine and one-half hours (fig. 164).

The angle of the sun's rays and the number of hours during which it shines upon us work together to make the earth and the air warmer in summer than in winter.

327. Daylight saving. During the past few years an active daylight-saving campaign has been developed. It is argued that the ordinary hours for professional and industrial occupations should not remain the same during all seasons of the year. It is desired to utilize natural light more fully during the period in summer when business hours begin at 8, 8.30, or 9 A.M. and daylight begins at from 4 to 5 A.M. The new legislation is not designed necessarily to lengthen the number of hours during which any one person works, but rather to leave more free time for leisure occupations. The opponents of the plan claim that no material advantage results from the legislation upon this question; that there is ample light during spring, summer, and autumn for a full day's work; that leisure hours can be arranged by those who desire them and can use them; that there is an irreducible amount of time needed for sleep, meals, and recreation upon which the plan may encroach; and that agriculture and

an athlete who can run one hundred yards in ten seconds could run around the earth for one year without stopping, he would in that time circle the earth over seven times. If he could run at the same rate from the earth to the sun, it would require over five hundred years for him to make the trip one way; and we need not discuss his return trip, for long before his return human history would have undergone fundamental changes and our generation would be all but forgotten. It is said that the shortest time in which anyone has made the trip around the earth is thirty-seven days. At that rate it would take one year to reach the moon, four hundred years to reach the sun, and one hundred million years to reach the nearest star.

Possibly a better illustration is the time it would take for sound to travel from the sun to the earth. As a matter of fact, sound could not travel from sun to earth, since there is no atmosphere for it to travel through, the earth's atmosphere probably extending only a little more than a hundred, or at most a few hundred, miles from the earth's surface. In our atmosphere sound travels at the rate of approximately one mile in five seconds. At this rate, with an intervening atmosphere like ours, we should hear the reports of the explosions which occur on the surface of the sun after an interval of about fifteen years; that is, an explosion which occurred on the sun's surface at the time when you entered the first grade of school would be heard by you about the time you are graduated from college.

329. The earth's orbit and the size of the sun. The circumference of the earth's orbit is about 600,000,000 miles. When this number is divided by the number of seconds in the year, it is found that the earth moves in its orbit at the rate of about 18.5 miles per second. The orbit is so immense that the curvature in a distance of 18.5 miles is only about one eighth of an inch. This serves also to indicate how far we are from the sun.

When the distance of the earth from the sun became known it was easy to find the sun's actual diameter. The measurements which have been made show that its diameter is 866,000 miles. This means that the volume of the sun is more than a million

times that of the earth. In fact, if the earth were placed at its center, a tiny particle compared to the immense sun, and if the moon were revolving around it just as it does at present, the moon would be less than half the distance to the surface of the sun.

330. Source of the sun's heat. It follows from the enormous amount of light and heat energy received from the sun that the amount radiated by this great body must be beyond our imagination. The earth as seen from the sun would be a point in the sky and would intercept only $\frac{1}{2,000,000,000}$ of the amount of light the sun radiates. It is found upon computation that every square yard of the sun's surface is giving off energy at the rate of about 70,000 horse power. Its temperature, therefore, is so high that we have no adequate means of understanding it, though we can approximate its measurement. The temperature of the sun has been computed and shown to be about 10,000° F. at the radiating surface; and the interior is thought to be much hotter.

331. Storms on the sun. The sun's surface is disturbed by most violent storms (fig. 165), as might be anticipated from its great mass and extremely high temperature. Some of these storms produce what are known as sun spots, which in appearance are black spots ranging from a few hundred miles to fifty thousand miles across.

The sun should be regarded as a largely gaseous mass, which is in a state of wildest turmoil and confusion, with terrific storms involving masses of matter hundreds or even thousands of times as large as the earth, some moving on its surface with a speed of hundreds of miles a minute, others shooting up from it with a speed exceeding a hundred miles a second and ascending to a height of several hundred thousand miles. This idea of the sun is very different from that of the ancients, who imagined it to be a piece of burnished metal drawn across the sky by a chariot and horses and who also imagined this little earth on which we live to be the principal object in the universe.

332. Constitution of the sun. Although we are able to measure the distance, dimensions, and mass of the sun, until 1860 it was supposed that we should never be able to find out of what it is composed. The invention of an instrument called the spectroscope opened a new world of knowledge. Its operation depends upon the fact that when matter is in a gaseous state the kind of light which it radiates depends upon the composition of the radiating gas. For example, gaseous hydrogen radiates certain kinds of light, gaseous oxygen other kinds, and gaseous

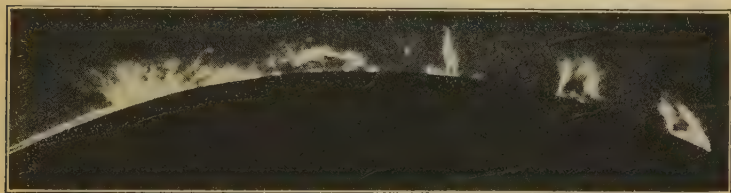


FIG. 165. Explosions on the sun's surface

Photograph by the Yerkes Observatory

iron, copper, etc. still other kinds. No two known substances in a gaseous state radiate exactly the same kinds of light, just as no two strings on the harp give forth the same sound.

The spectroscope is an instrument which makes it possible to analyze the light received from any source. When the light of the sun is analyzed, it is found that in its atmosphere there are certainly about half of the elements of which the earth is composed. Among them are such familiar things as hydrogen, carbon, oxygen, potassium, calcium, iron, nickel, copper, zinc, silver, tin, and lead. Most of the elements known on the earth which have not been found in the sun are the nonmetals, such as chlorine, iodine, sulphur, nitrogen, and phosphorus. Although they have not been found upon the sun, they probably exist there. There are a few heavy metals, such as gold, platinum, and perhaps mercury, which have not been discovered in the sun. These heavy substances probably lie so deep in its interior that the light from them does not get beyond its surface.

CHAPTER XXII

THE MOON, PLANETS, AND COMETS

333. Questions for discussion. 1. Does the moon shine by its own light? 2. Does the sun? 3. Does the earth? 4. Is the sun the source of energy for all the planets? 5. Why does the moon change its appearance from evening to evening? 6. What is the source of the moon's light? 7. Since both earth and moon revolve about the sun, how do you account for the fact that the moon is sometimes visible and sometimes not? 8. How could you make a simple telescope with which to study the moon?

9. What are the reasons for thinking that the moon is not inhabited and does not produce crops of plants as the earth does? 10. What is an eclipse of the moon? 11. What arguments are presented to show that Mars is inhabited? 12. What planets can be seen without a telescope? 13. How can a planet be distinguished from a star? 14. Can the planets always be found in the same place in the sky?

334. The moon, its size and distance. Next to the sun, the moon is the most conspicuous object in the heavens, and it is always an object of wonder and interest. Every thoughtful person has looked at the moon in wonder and has noted its apparent change of shape during the month. Each month when it is a "new moon" it seems to be a thin crescent, with the tips turned toward the east (fig. 166). A few days later it has the form of a semicircle, and in another week it appears to be perfectly round. Then it gradually changes in the reverse order to the semicircle and to the thin crescent, with the tips now turned toward the west. Primitive peoples noted the regularity of these changes and measured their time by them. The American Indians would say that in so many moons this or that religious festival or other occurrence would take place. In diameter the moon is 2163 miles, approximately one fourth that of the earth. Its distance from the earth ranges from 221,000 to 253,000 miles.

335. Phases of the moon. The moon is not a light-giving body except in the sense that it reflects light which shines upon it from the sun. It moves around the earth and it moves with the earth around the sun. Its changing positions relative to the earth and sun cause its changing appearances, which we call its phases.

When the new moon first appears as a thin crescent in the west, the moon is almost in a line from us to the sun. Since only the side of the moon toward the sun is lighted, the dark side is toward us, though since the moon is not exactly between us and the sun we see a thin edge of the lighted side. As the moon goes around the earth, night after night it is seen to be at a greater angular distance from the sun, and more of the lighted side is seen from the earth. A week after new moon it is at an angle of 90 degrees from the sun's direction. It is in the south when the sun is in the west. Also we can see one half

of the light side and one half of the dark side. In another week the moon has changed its position by 90 degrees more and is on the side of us opposite from the sun. We can therefore see the whole of the lighted side of the moon. This is full moon.

During the next two weeks the moon continues its course around the earth and gradually comes again to the relative position which it occupied at new moon. During this time the visible part of the lighted side of the moon decreases just as it increased during the preceding two weeks.

336. Amount of light from the moon. It sometimes seems that the amount of light received from the moon is almost as great as that which is received from the sun. This conclusion

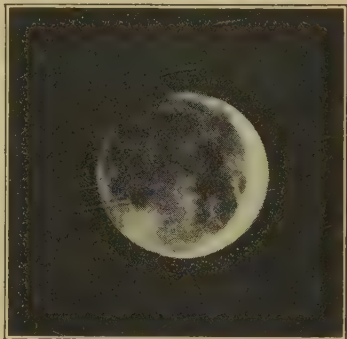


FIG. 166. New moon

The moon in its second day, also the old moon in dim outline. Photograph by the Yerkes Observatory

is incorrect, for the brightest full-moon light is only about $\frac{1}{500,000}$ of the brightness of sunlight. Taking the whole month into consideration, the amount of light and heat received from the sun is about 2,500,000 times the amount received from the moon; or, in other words, the earth receives as much light and heat from the sun in thirteen seconds as it receives from the moon during a whole year. It follows from this that it is not reasonable to suppose that the moon has any important effect upon the earth's climate. This conclusion is confirmed by observations which have been made by the weather bureaus of various countries for many years. It is found from the records that there is no certain relationship between the phases of the moon and the characteristics of the weather.

337. Atmosphere and water on the moon. The moon differs from the earth in the very important point that it has no atmosphere surrounding it. This is shown by the fact that the illuminated part of its surface is always seen undimmed by clouds, fog, haze, or other atmospheric phenomena.

There is no water upon the moon's surface. When observed through powerful telescopes, all that side of the moon which is toward the earth is seen to be simply a rocky and desolate waste. It has sometimes been supposed that on the side of the moon which is never turned toward the earth there might be water and conditions like those which make the earth habitable; but this is impossible, for if there were an atmosphere on the other side it would quickly spread all round, and part of it would appear on the side of the moon toward the earth. If there were water on the other side and no atmosphere, at least a part of the water would be evaporated and would produce an atmosphere of water vapor, part of which would pass to the side toward the earth.

338. Erosion and craters. In consequence of the fact that the surface of the moon has neither atmosphere nor water, it has not undergone the process of erosion. There is no reason to suppose that rains and snows have ever dissolved the rocks or that winds have ever scattered their disintegrated remains in

the valleys. The surface of the moon is covered with great circular pits called craters (fig. 167), some of which are as much as a hundred miles in diameter and two or three miles deep. There are also mountains of spirelike character and of great height.

The explanation of the lunar craters is not a simple matter, and astronomers are not entirely in agreement on the question. Their great size, the absence of any water on the surface of the moon, and the absence of distinct lava flows make it doubtful whether they are closely similar to the volcanic craters which are now found on the surface of the earth.

339. Climate of the moon. The moon revolves around the earth, and the earth and moon revolve around the sun at a distance four hundred times their distance from each other. Consequently the average distance of the moon from the sun is about the same as that of the earth, and, other things being equal, its climate would be about the same as that of the earth. There are two important factors, however, which make it entirely different. The first of these is that it turns on its axis very slowly; in fact, it rotates in such a way that the same face of it is always turned toward the earth, and its day is twenty-



FIG. 167. The moon at six days

Photograph by the Yerkes Observatory

nine and one half of our days. If there were no other differences, the daily change in temperature would be enormously greater than on the earth. If the earth's day were equal to that of the moon, the temperature would probably fall below the freezing point every night, even at the equator, and it would ascend to unusual heights during the day.

The second reason why the climatic changes of the moon are different from those of the earth is that it has no atmospheric covering. The sun's rays are never cut off by clouds or even diminished by the partial screen of an atmosphere, and consequently the temperature rises very high in the long interval between sunrise and sunset, which is nearly fifteen of our days. After the sun is set, the other extreme of temperature soon begins to develop. There is no atmosphere to retain any heat which has been accumulated during the day. The temperature falls in the course of two or three hours from a maximum reached in the daytime, which is supposed to be near the boiling point, down to what is probably near freezing point. In the course of one of our days it descends probably far below our zero and remains there the rest of the night.

As a further consequence of the absence of both water and atmosphere on the moon, and of the extremes of temperature, it follows that there can be no life upon it. It is believed by astronomers that the conditions on the moon have never been essentially more favorable for life than they are at present, and that they will not become more favorable in the future unless in some way its mass increases so that it may hold an atmosphere around it by the power of its gravitation. The moon is a dead world, which has pursued its course around the earth and, with the earth, has revolved around the sun through long ages. It illuminates the earth part of the time with its feeble rays and produces the tides, which rush in and out twice a day upon the shores of the oceans, but otherwise it has little effect upon the earth or upon its inhabitants.

340. Eclipses. The earth casts a shadow which extends, of course, in the direction opposite to the sun. When the moon

passes into this shadow it is eclipsed, for then the direct light of the sun is cut off. The moon would be eclipsed every month at full moon if its orbit were not somewhat inclined to the earth's orbit, so that ordinarily it passes above or below the shadow of the earth.

The moon casts a shadow, which now and then strikes on the earth and produces, in a limited region, an eclipse of the sun.

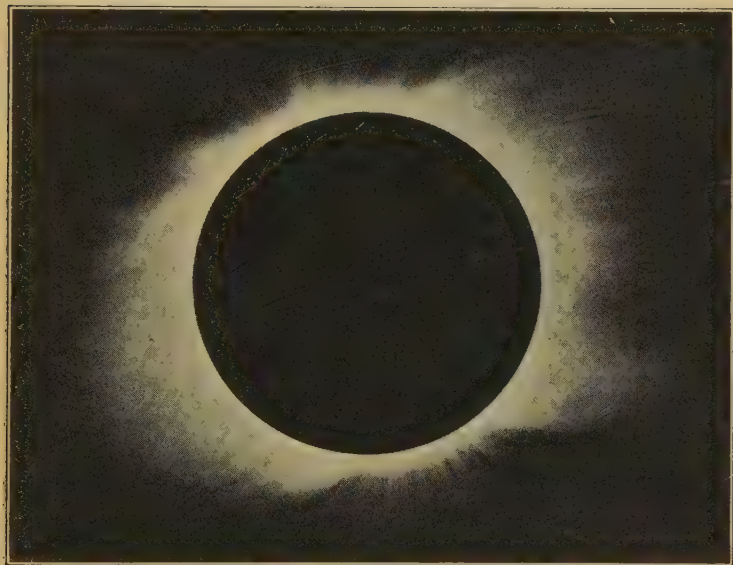


FIG. 168. The sun at total eclipse

The picture shows the crown, or corona, around the sun. Photograph by the Yerkes Observatory

For persons in the path of the shadow the sun's light is cut off (fig. 168), and for a short time, usually only a minute or two, the sun is invisible.

The accuracy with which astronomers know the distance, dimensions, and motions of the moon is shown by the fact that they are able to predict with a high degree of accuracy when eclipses will occur. Not only can it be determined when an

eclipse will occur but from what points on the earth's surface it will be visible (fig. 169). Computations of eclipses are made many years in advance, and astronomers organize expeditions at great expense to go to favorable places for observing them.

Eclipses of the sun have been used in the most interesting manner to locate in our system of reckoning time some of the

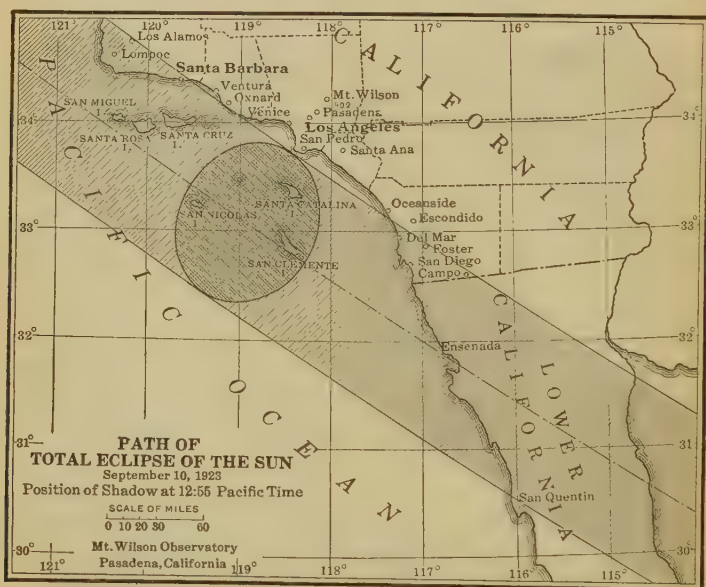


FIG. 169. The total eclipse of 1923 .

dates of ancient history. In certain cases writers have mentioned facts occurring many centuries ago, before our present system of reckoning time was in use, and have stated that certain events occurred at a time of a total eclipse of the sun in a definite place on the earth's surface. The dates of these eclipses have been determined by astronomers by counting back across the centuries for more than two thousand years; and thus in our system of reckoning time the dates of events which were given in some other system have been determined for historians.

341. Planets which revolve about the sun. Next to the moon the planets are most readily observed. The eight planets, of which the earth is one, revolve about the sun. They are seen by means of light reflected from the sun instead of by means of their own light as is true of the sun and other stars. It was supposed by the ancients that the apparent motion of the sun was due to the actual revolution of the sun around the earth.

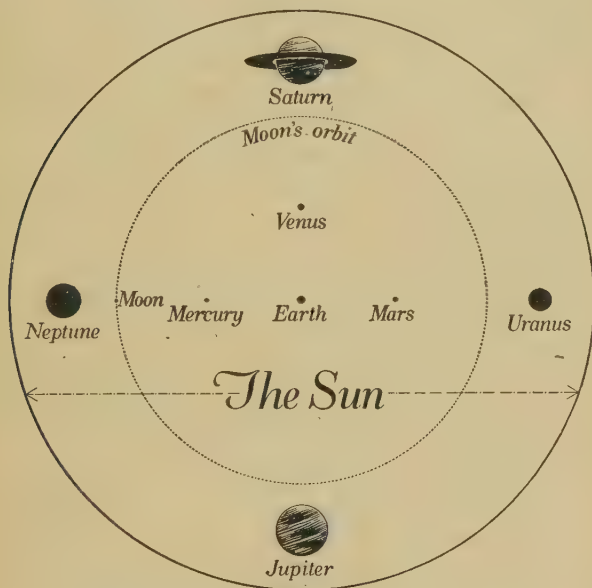


FIG. 170. Diagram of relative sizes of the sun, moon, and planets

To most of them it did not seem possible that any other body could be enormously greater than the earth and that the earth should revolve around it. But with the improvement of astronomical instruments and methods it has been found that the earth revolves around the sun in a path which is almost circular.

The seven other planets which revolve around the sun move in the same direction as the earth and almost in the same plane. It is difficult to represent the orbits of all the planets on the

same scale upon the page of a book, because those which are farthest from the sun are at such a great distance compared to those which are nearest. Their names, their proportionate diameters and distances from the sun, their periods of revolution around the sun (their years), and their periods of rotation (their days) are shown in figure 170 and in the table on this page.

It is seen from the table that those planets which are near the sun complete their journey around it in a very short time. If one were living on the planet Mercury and counted his age in terms of its years, he would be four times as old as he would be if he were living on the earth. On the other hand, the remote planets move in such large orbits and so slowly that immense intervals of time are required for them to make their journey around the sun. In terms of the year of Neptune we should all still be very young.

IMPORTANT FACTS CONCERNING THE PLANETS

PLANET	DIAMETER	DISTANCE FROM THE SUN	YEAR	DAY
Mercury	2,765 mi.	36,000,000 mi.	3 mo.	?
Venus	7,726 mi.	67,200,000 mi.	7 mo.	?
Earth	7,913 mi.	92,900,000 mi.	12 mo.	24 hr.
Mars	4,312 mi.	141,500,000 mi.	23 mo.	24 hr. 37 min.
Jupiter	84,570 mi.	483,300,000 mi.	12 yr.	9 hr. 55 min.
Saturn	69,780 mi.	886,000,000 mi.	29.5 yr.	10 hr. 14 min.
Uranus	31,900 mi.	1,781,900,000 mi.	84 yr.	?
Neptune	34,900 mi.	2,791,600,000 mi.	165 yr.	?

NOTE. The moon (not a planet) has a diameter of 2163 miles. The sun (a star) has a diameter of 866,540 miles.

342. Mercury and Venus. The planets nearest the sun are Mercury and Venus. The diameter of Mercury is a little less than three thousand miles, and, like the moon, its mass is so small that it cannot retain an atmosphere. Since it is much nearer to the sun than it is to the earth, it gets proportionately more light and heat, nearly seven times as much per unit of

area as we receive. This fact, associated with the fact that it has no atmosphere, means that the day side of Mercury is intensely heated. Some vague markings which have been observed upon its surface seem to indicate that it always presents the same face toward the sun, just as the moon always presents the same face toward the earth. If this is true one of its sides is perpetually burned by the intense rays of the sun, while the other is in perpetual night and, consequently, very cold.

The planet Venus has a diameter of a little more than seventy-seven hundred miles and is therefore nearly as large as the earth. Observations show that it has an atmosphere comparable in amount to that which surrounds the earth; for example, when Venus passes between the sun and the earth it is seen to be surrounded by an atmospheric ring which is illuminated by the rays of the sun. Venus is in many respects similar to the earth, and the possibility of its being inhabited by creatures similar to those on the earth is greater than in the case of any other planet. Its year is only a little more than half that of the earth, while it receives per unit area about twice as much light and heat from the sun as does the earth. The length of its day is not known; but if it is approximately the same as that of the earth, the conditions on Venus are in a general way similar to those on the earth, the chief difference being that the seasons are shorter, while the climate is considerably warmer. In fact, if the earth were at the distance of Venus, its average temperature would be 150° F. instead of 60° F., as it is at present.

Venus is the most conspicuous object in the heavens besides the sun and moon. When it is at its greatest brilliancy, as evening or morning star, it gives enough light to make buildings cast perceptible shadows. It is not always visible; for when it passes between the earth and the sun or around to the part of its orbit opposite the sun, it is obscured, or lost in the sun's more brilliant rays. Venus, an evening star in the latter part of 1924, will be so again thereafter at intervals of one year and seven months. Its appearance as morning star is intermediate between its appearances as evening star.

343. The red planet Mars. The best known of all the planets is Mars. The reason for this is that it is relatively near the earth and well situated for observation, and also that it has a thin atmosphere, which permits us to obtain good views of its surface. The diameter of the planet is about four thousand miles, or one half that of the earth. Conspicuous markings on its surface have been recorded for about two hundred years, and it has been found by watching them that the day of the planet is a little longer than that of the earth. Its axis of rotation, too, is inclined to the plane of its orbit to about the same amount as the axis of the earth is inclined to the plane of its orbit. Consequently the day and night and seasons of Mars are much like those of the earth except that the seasons are twice as long. The principal difference is due to the fact that Mars is farther from the sun and receives per unit area only 44 per cent as much light and heat from the sun as are received by the earth.

The general surface of Mars is described as a dull brick red. There are on it, however, large irregular areas (fig. 171) that have a brownish and sometimes a greenish color. There is certainly no large body of water upon the planet, and consequently the climatic conditions must be very different from those of the earth. It is extremely probable that there is some water on Mars, for during the winter of either of its hemispheres there appears around its pole a white mantle or cap, often covering an area approximately as large as the United States. This white mantle generally appears rather quickly; that is, in the course of two or three days. It remains during the long winter of Mars, and as spring approaches and "the sun mounts daily higher in its sky," the polar cap gradually disappears. The fact that the snow disappears from the poles of Mars as the spring approaches means in the first place that it is probably thin, and in the second place that the atmosphere above it is probably dry so that rapid evaporation takes place.

344. The "canals" upon Mars. Interest in Mars received a great stimulus in 1877, when markings upon it were discovered

by Giovanni Schiaparelli, an Italian astronomer. The markings which he observed appeared to be very long, straight, and narrow. He called them *canali*, which unfortunately was translated into English as "canals." This led some people to conclude that upon the surface of Mars there is an immense network of irrigation ditches, which, of course, could only have been made if the planet were inhabited by highly intelligent beings.

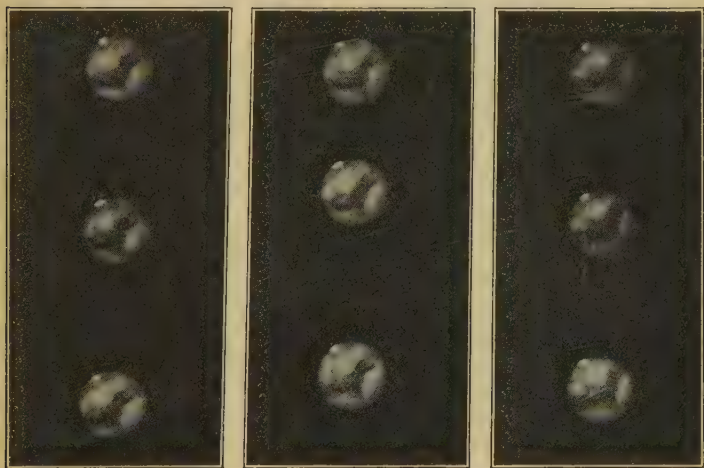


FIG. 171. Mars

A series of photographs by which the rotation of Mars is shown. Only a few seconds intervened between the three photographs of each vertical row. An hour and twenty-two minutes intervened between the upper left-hand and the lower right-hand photograph. Photographs by the Yerkes Observatory

The American astronomer Lowell was also convinced of the reality of the markings. He said that the markings were about 20 miles wide and from a few hundred miles to 3500 miles long. He thought they were not canals but streaks of vegetation which grew along the banks of irrigating ditches. He suggested that along the middle of one of the so-called canals there might be an irrigation ditch or canal with smaller ditches leading off to the sides, which together would irrigate a tract of country

from 20 to 50 miles in width and as long as the canal. This interpretation also implies the existence of highly intelligent creatures on the planet.

The conclusions of Lowell have not obtained very wide acceptance among astronomers because, in the first place, the observational data are not well established, and, in the second place, the interpretation of them cannot as yet be proved. There are upon Mars conditions of temperature and moisture which would seem

to us to make intelligent life impossible.

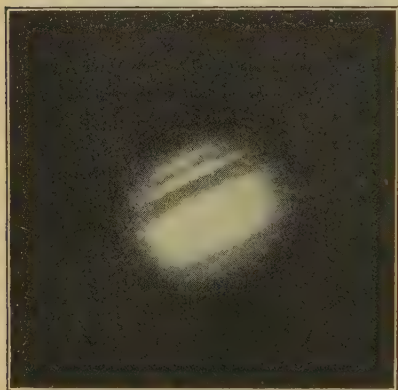


FIG. 172. Jupiter

Cloudlike bands appear and disappear on this planet from time to time. Photograph by the Yerkes Observatory

345. Jupiter. Jupiter is the greatest of all the planets and is in volume more than one thousand times as large as the earth. It has no fixed markings upon its surface, but there are great clouds, sometimes one thousand miles across, which develop and disappear in rapid succession (fig. 172). An interesting consequence of Jupiter's great dimensions and rapid rotation (its day

is nine hours and fifty-five minutes) is that it is very much bulged at the equator and flattened at the poles. Its elliptical form and the belts across its surface can be observed by means of a telescope a few inches in diameter.

Jupiter has a large number of moons. The first four were discovered by Galileo in 1610 with the first telescope used to observe the facts regarding the heavens. These four moons were in fact the first heavenly bodies discovered with the aid of an instrument. The fifth satellite of Jupiter was discovered in 1892, and since then five other small moons have been found. The largest ones are larger than the planet Mercury, and the

smallest ones are less than one hundred miles in diameter. The eight which are nearest the planet revolve around it from west to east, which is the direction in which the planet rotates, but the two most remote revolve in the opposite direction.

The planet Jupiter was visible as a conspicuous object in the evening sky in the second half of 1924. It will be visible in the evening sky at intervals of one year and one month thereafter, and in the morning sky at intermediate periods. It can be distinguished from the stars by the fact that it is more brilliant

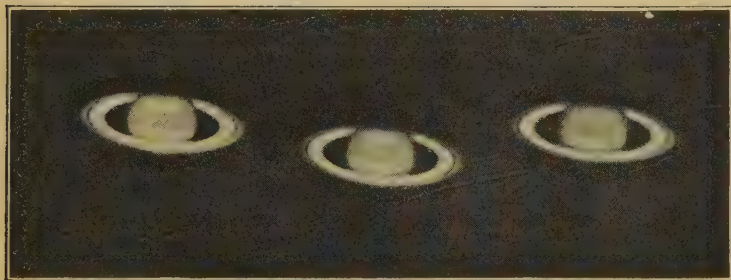


FIG. 173. Saturn

Three photographs showing the peculiar ring about the planet. Photograph by the Yerkes Observatory

than any fixed star and shines with a steadier light, and a few nights' observation will show that it is moving among the stars.

346. Saturn. The planet Saturn is a little smaller and somewhat less dense than Jupiter. It has nine and possibly ten satellites, one of which revolves around it in a direction opposite to the others. The thing that distinguishes Saturn from all the other planets is the enormous ring system which surrounds it (fig. 173). The rings have the appearance of being a solid mass. They are in reality swarms of particles of unknown size (but probably small) which circle around the planet in the plane of its equator and, because of their great numbers, appear solid, just as a cloud floating around a mountain peak appears from a distance to be as solid as the mountain itself. The dis-

tance across the outside ring is about 11,000 miles. There is a gap of about 2000 miles between it and the next ring, which is approximately 18,000 miles across. This second ring is as bright as the planet itself. Inside it and joining it is a very faint ring about 11,000 miles across. The inner edge of this ring is about 6000 miles from the surface of the planet. Although these rings are of vast extent, in the plane of the equator they are very thin, and when they are seen edgewise to us they are barely visible even in the largest telescopes. It is certain that they are not more than 100 miles thick, and probably not more than 50.

347. The discovery of Uranus. Only six planets were known until the year 1781, when William Herschel, a German musician who had migrated to England, discovered the planet Uranus. Herschel secured a book on astronomy and became greatly interested in the science. He immediately resolved to procure a telescope and explore the heavens for himself. In those days (about 1760) telescopes could not be purchased as at present, and it was necessary for Herschel to make them. He first studied mathematics in order to understand the theory of making the curved surfaces for his mirrors. In spite of this difficult study, which was necessary before he could begin to construct a telescope, he mastered the task. He then began to grind mirrors, making one after another, each better than its predecessor. With a telescope of his own make, on an evening in 1781, Herschel detected an object in the sky which was invisible to the unaided eye and which appeared slightly different from a star. After following it a few nights he found that it was moving with respect to the stars, which proved that it was a member of the solar system. At first he thought it was a comet, but a few weeks' observation determined that it was a previously unknown planet. This aroused the greatest interest, not only among scientific men but among people in general. Herschel was recognized as one of the world's greatest astronomers.

The planet Uranus has a diameter of a little more than thirty thousand miles. Four moons have been discovered revolving around it in planes which are almost at right angles to the plane

of the planet's orbit. Like Jupiter and Saturn it is of low density and is in an early stage of its development.

348. The discovery of Neptune. The discovery of Neptune is one of the most striking things in the history of science and proves the high accuracy of astronomical methods.

After a planet has been observed a few weeks its orbit can be computed, and the position it will occupy at any future time can be determined. Its motion depends not only upon the attraction of the sun but, to some slight extent, upon the attraction of other planets for it. After Uranus had been discovered its orbit was computed and the place it would occupy at future dates was predicted. In 1820, or about forty years after its discovery, it was found to be deviating very slightly from its predicted position. Between 1830 and 1840 the deviation had become still greater. The cause was a question of the greatest interest to astronomers.

The problem of finding the position of a more remote planet which by its attraction might have disturbed Uranus from its position by the observed amount in these sixty years was one of such great difficulty that the foremost mathematicians of the world did not even attempt to solve it. It was, however, boldly attacked by two young men who had just graduated from college—Mr. J. C. Adams of Cambridge, England, and Mr. Joseph Leverrier of Paris. Each worked independently of the other and, in fact, without announcing that he was attempting to solve the problem. Adams completed his work first, and found that if there was in a certain part of the sky another planet farther out from the sun than Uranus, it would have produced the deviations in the motions of Uranus which had been observed. He attempted, without success, to have it sought for both at Cambridge and at the Royal Observatory in Greenwich. In the meantime Leverrier, who had finished his computations by a method entirely different from that used by Adams, arrived at essentially the same conclusion. He wrote to a young German astronomer, Galle, and asked him to search for the suspected unknown planet. Galle impatiently waited for

night so that he could begin the hunt, and soon after darkness had come he had found the unknown body in almost the exact position assigned to it by both Leverrier and Adams.

Neptune is nearly 3,000,000,000 miles from the earth and can be seen only with telescopic aid. Its distance is so great that more than four hours are required for its light to come to us, though light travels at the rate of 186,000 miles per second, or about 10,000,000 miles per minute. Yet it is bound to the remainder of the system by the invisible bonds of gravitation.

349. Comets. The planets are fixed in dimensions and shape and revolve around the sun in relatively simple orbits. There are other bodies, the comets, which differ in all these respects. They are not often visible and usually for but a short time. They often change their dimensions enormously and move in most peculiar ways. Until a comparatively short time ago they were regarded by people with superstitious terror and were supposed to foretell disaster.

The typical comet (fig. 174) is composed of a head whose diameter may range from a few thousand miles to a million miles. Inside of the head there is generally a brighter, starlike nucleus, and streaming out from it in the direction opposite from the sun there is usually a tail whose length may be as much as a hundred million miles.

About four hundred comets have been observed since the invention of the telescope, most of them too faint to be seen without optical aid. Their orbits lie in all sorts of directions, and they are usually very elongated; in fact, most of them are so exceedingly elongated that at their remotest points from the sun they are many times the distance of Neptune, and it may be that some of them actually recede to the distance of the stars.

When a comet approaches the sun its tail streams behind like the smoke from a locomotive, but when it again recedes from the sun the tail goes out ahead like the rays from the headlight on a misty night. There is much speculation as to the causes of the phenomena observed in comets. It is supposed that there is some sort of an electrical repulsion, and probably also pres-

sure of the light radiated by the sun, which drives off the minute particles of which the tail of a comet is composed and makes them stream out ahead in the direction opposite to the sun.

350. Visible comets. While most comets are visible only through a telescope, some occasionally appear in great splendor. One of these, known as Halley's comet, returns after periods of



FIG. 174. Halley's comet

Note that the tail of the comet extends and slowly disappears at a great distance across the sky. The light spots are photographs of stars, which appear elongated, owing to changes of position while the picture was being taken. Photograph by the Yerkes Observatory

about seventy-five years. Its orbit was first computed by Halley, who showed that the comet which appeared in 1682 ought to return again about 1757. He thus predicted its return and described the circumstances of its appearance. Most people laughed at this; but as the time drew near, scientific men who knew the soundness of the principles on which the prediction was based became immensely interested in the question of the return of the comet. Halley's prediction was verified, for not only did the comet return, but twice since it has passed near

the sun and become visible from the earth—the last time in 1910. Its next appearance will be in 1986. When it was near the earth its head appeared to be nearly as large as the moon, and its tail stretched one third the distance across the sky. In spite of these great dimensions it was not very conspicuous. Other comets have been seen which were so bright that they were visible even in the daytime.

The superstitions regarding the evil influences of comets have been dissipated by the advance of science, but many people still fear that if a comet should actually strike the earth, all life on the earth might be destroyed. The result, of course, depends primarily upon the mass of comets, and about this nothing is known with certainty. If the earth should pass through the tail of a comet, as has happened a number of times in the last century, no harm would be done. Even if the earth should collide with the head of a comet, it is not probable that there would be serious injury to the earth or the people who live upon it.

CHAPTER XXIII

THE STARS

351. Questions for discussion. 1. Are some of the stars like our sun in the sense that they are centers of great solar systems? 2. Are there stars which are larger and which give off more light than our sun? 3. Why do we not receive more light and heat from the larger stars? 4. By use of the text discussions and a star chart see if you can locate the following: the Big Dipper, the Pleiades, the North Star, Cassiopeia, Pegasus, Orion, the Milky Way. 5. What is the "milky way"? 6. What is a shooting star? 7. How long a time is required for light from the nearest star to reach the earth?

352. Nature and distance of the stars. It was once supposed that the sky is composed of a more or less solid substance in which the stars are embedded as jewels and that the whole structure revolves about the earth. We now know that the earth turns on its own axis and that it revolves in its orbit about the sun. We also know that the other bodies have motions more or less similar to those of the earth. The stars are so far away from us that their position relative to one another seems to us to change but little. The position of the planets relative to the stars changes constantly. By this fact the planets, although they look like stars and are often so called, can readily be distinguished from the stars; the stars form a relatively permanent pattern, but after a few days or weeks the planets can be seen to have changed position among them.

The stars are immense suns, most of those we see being much larger than our sun and millions of times larger than our earth. In light-giving power some stars are 100 times, some 1000 times, and some even 10,000 times, as great as our sun. Our sun would be invisible without telescopic aid if it were as remote from us as are most of the stars which we see.

The sun gives us more light and heat in a second of time than all the stars together do in fifty years. Since, in many cases, they are larger than our sun they must be exceedingly remote. The nearest one which can be seen from the United States is 5,000,000 times as far away as we are from the sun. It is so far away that four and three-tenths years are required for its light to come to us at the rate of 186,000 miles per second. Suppose that a ray of light leaves this nearest star at the time you begin your college course. You will, if successful, have completed your four-year college course and will have had about half a year out of college when the light reaches the earth. Since most of the stars we see on a clear evening are many times this distance, we are made to feel almost helpless in our effort to understand the meaning of space. Some stars are so far away that light reaches us a thousand years after it is radiated, and the telescope shows stars which require many thousands of years for their light to reach us.

353. Stars of different magnitude. The 20 brightest stars are taken together and are called stars of the first magnitude. They are about two and one-half times as bright as the next group, which are called stars of the second magnitude. Examples of these are the Pole Star and the stars in the Big Dipper. In the whole sky there are 65 stars of the second magnitude. Stars of the second magnitude are two and one-half times brighter than those of the third, of which there are 190. Similarly, the third magnitude is two and one-half times brighter than the fourth, and so on. The faintest stars which can be seen with the unaided eye are of the sixth magnitude. There are in the first six magnitudes all together about 5000 stars, only half of which are above the horizon at one time. Ordinarily one cannot see more than 2000 stars at one time on a clear evening. Under high magnification, however, innumerable stars may be seen, and sometimes these appear merely as great masses of nebulous matter (fig. 175).

354. Shooting stars and meteors. On almost any cloudless night, if one is watching the heavens, he will occasionally see a

so-called "shooting star." On such an occasion it appears to the observer that one of the stars has suddenly left its place and shot across the heavens for a short distance, disappearing at the end of its path. This is not really the case, because after the shooting star has disappeared, it is found that all the true stars are in their places just as before.

The "shooting star" is not a star at all, but something quite different. In the space through which the earth is passing there are many small particles of matter, each moving in its own orbit, and often with great velocity. As the earth sweeps along it encounters many of these particles, and as they fly through the earth's atmosphere at high speed the friction between them and the atmosphere produces enough heat to cause them to become white-hot and finally to vaporize. All of this occurs

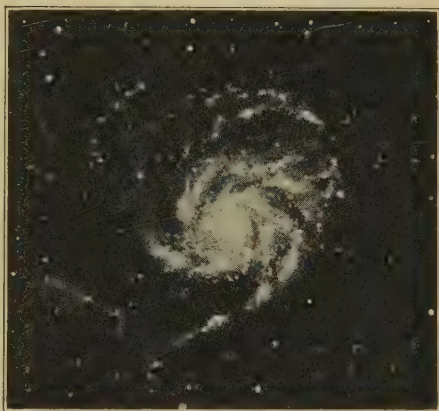


FIG. 175. Spiral nebula

Photograph by the Yerkes Observatory

in the higher layers of the atmosphere, and it is so far away from us that the bright particle has the appearance of a star.

Occasionally the earth encounters a body of matter so large that it is not vaporized by passing through the atmosphere, though it is made glowing hot. Such an object is called a meteor. Meteors occasionally strike the surface of the earth, but they are so rare that very few people have the opportunity to see one outside of a museum.

355. The constellations. Any observer will note that the stars are grouped in such ways that the brighter stars often form more or less conspicuous figures. For example, the Big Dipper

(fig. 176) and the Pleiades, as well as several other prominent groups, are recognized by most people. The more prominent groups of stars or constellations were given fantastic names by ancient peoples. The imagined forms of constellations furnished the basis of many primitive myths, and although the myths have passed away the names are still used.

356. The Milky Way, or Galaxy. Everyone has observed the great band of stars which extends across the entire sky and is

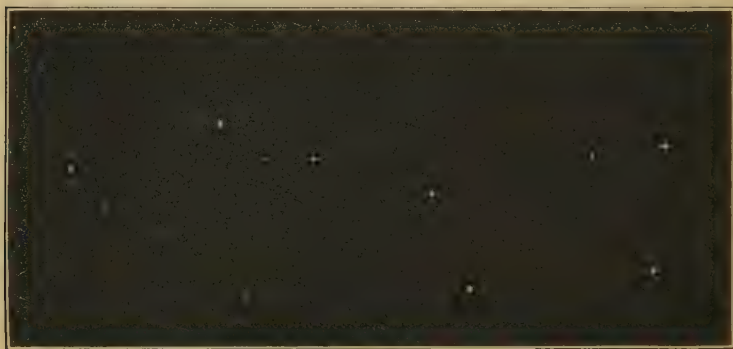


FIG. 176. The Big Dipper

Photograph taken so as to omit almost all stars except those which compose the dipper. Note that the second star from the left is a so-called double star.

Photograph by the Yerkes Observatory

known as the Milky Way (fig. 177) because its stars are so numerous as to give the appearance of an immense stream of milk. The hundreds of millions of stars are grouped more or less definitely into aggregations or constellations. There are probably at least five hundred millions of them, and all together they are known as the Galaxy. The sun at the present time is somewhere in the interior of the Galaxy.

357. Stars visible in October, November, and December.¹ Within the limits of so brief an outline as here presented it is

¹ There are several types of star charts or cards which may be secured from book dealers. Some of these are so constructed that they may be set for any day of any month during a period of years. Such charts or cards should be

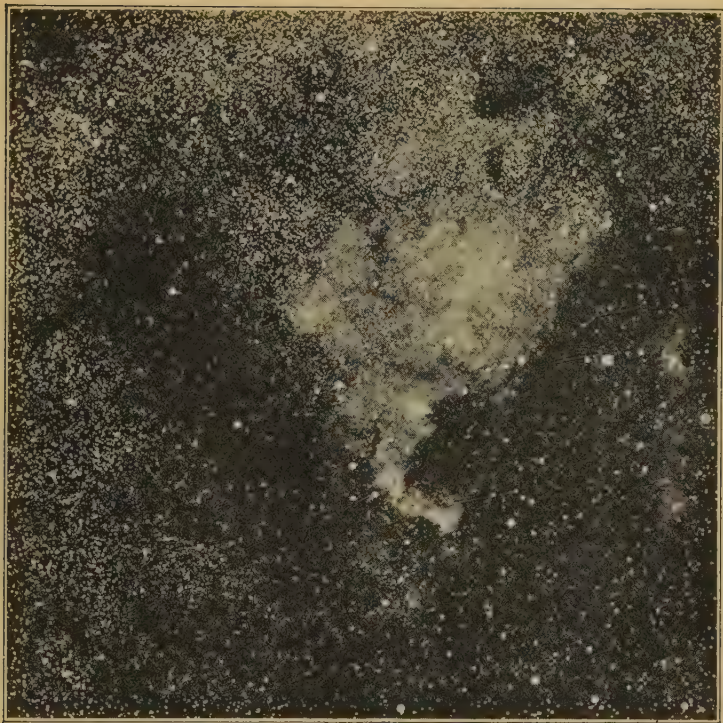


FIG. 177. A gaseous nebula called North America

This peculiarly shaped nebulous mass lies in the Milky Way. Photograph by the Yerkes Observatory

not possible to do more than suggest a few of the more important and easily recognizable constellations of our sky, and to show how further studies may be made by those who are

used in connection with this discussion in order that each pupil may make his own study of the stars. By use of such a chart this part of the text will serve as a guide for observations, but it should not be used as the basis for mere memory work.

The discussion of constellations which composes the rest of this chapter will be found stimulating and interesting to many students. It has, however, been placed at this point and with this arrangement so that it may be easily omitted by those who do not have time to include this study in their course.

interested. It is assumed that the time for the position named is the middle one of the three months and about eight o'clock in the evening. For the first of the three months each star should be found about 15° east of the positions indicated, and for the third, about 15° west.

The North Star and the Big Dipper are easily located. The Big Dipper is composed of a group of bright stars so arranged that the handle and bowl of the dipper are visible in the northern sky. The stars of the dipper move in such a way that the whole dipper seems to revolve with the handle turning on the dipper point as an axis. The Big Dipper is a part of the larger constellation known as Ursa Major, or the Great Bear, referred to later. If a line is drawn through the two stars of the part of the bowl opposite the handle, and this line is extended above the bowl a distance about six times the distance between the two stars, this line will lead to a star of similar size and clearness, the North Star, or Pole Star. These two stars of the Big Dipper are known as the "pointers." For unknown ages the Big Dipper and the Pole Star have been used as guides by travelers at night.

If in the month of November, about eight o'clock at night, the observer faces the north, he will find above the Pole Star, about three fourths of the distance from the north horizon to a point directly overhead, a "zigzag" of seven stars of the second and third magnitudes which constitutes the constellation Cassiopeia, known as "the woman in the chair." To most people it does not look like a chair, but like the letter W. The bright star which forms the bottom of the right-hand half of the W is a "double star," as is also the one near the middle of the third stroke of the W. The double nature of these stars cannot be determined except by use of a telescope, but it is interesting to know that in the second case the two stars revolve around their common center in a period of about two hundred years. At the time when Cassiopeia is visible, as indicated above, the Big Dipper is directly under the pole and so near the horizon that it cannot be observed unless the sky is very clear.

If the observer faces the south, and looks a little to the west of the south point and up about two thirds of the way between the horizon and the zenith, he will see the constellation Pegasus, which can be recognized from the fact that in it there are four stars which form a large square known as the "Great Square of Pegasus." There are no other conspicuous stars in this region of the sky.

West of Pegasus, almost straight west from the observer, and nearly halfway up from the western horizon to the zenith is a diamond-shaped group of stars in the constellation Delphinus. This group is often called "Job's Coffin."

358. Stars visible in January, February, and March. In February, at eight o'clock in the evening, directly to the east of the Pole Star is the Big Dipper. To the west of the pole is Cassiopeia. If the observer faces the south he will see a brilliant star just east of his meridian and about one third of the way up from the horizon to the zenith. This is the great first-magnitude star Sirius, in the constellation Canis Major, or the Great Dog. Although this star is comparatively near to us, only three or four being nearer, it requires eight and two-fifths years for its light to come to us, and its distance is 50,000,000,000,000 miles. It is approaching us at the rate of about four-miles per second; but this change, which amounts to more than 100,000,000 miles in a year, is of little relative consequence and will make no noticeable difference in its brightness for thousands of years. If Sirius should suddenly cease to exist, we should continue to see its light for over eight years.

A little farther to the east, and somewhat higher than Sirius, is another first-magnitude star, Procyon, in Canis Minor, the Lesser Dog. Almost straight north of Procyon, and about straight east from the observer, are two stars of about the same magnitude, in the constellation Gemini, the Twins. The more northerly of the two is called Castor; the other one is Pollux. About ten degrees southwest of Pollux is an open cluster of stars called Præsepe, the Beehive, which can easily be seen on a clear and moonless night.

Immediately west of the meridian, and about halfway from the horizon to the zenith, is the group of stars known as Orion (fig. 178), located in the most brilliant part of the sky. In the legends of the ancients Orion was a giant and a mighty hunter

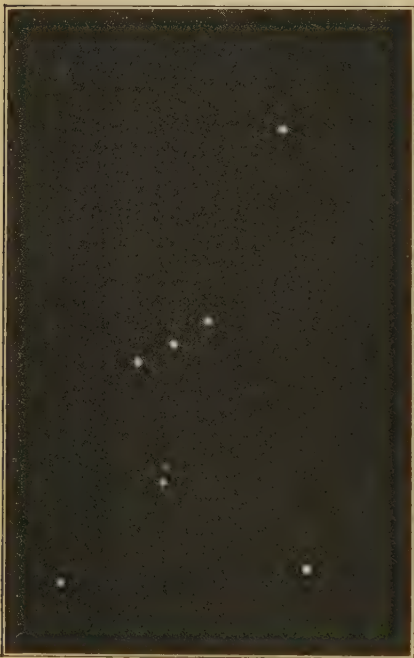


FIG. 178. Orion

In making this photograph the camera was arranged so as to omit most of the stars of the region, thus showing the imaginary warrior, Orion, more clearly. Photograph by the Yerkes Observatory

who in the sky stands facing Taurus, the Bull, which is somewhat to the west of him. In Orion there are three stars in a straight line running from the upper right to the lower left. They constitute the belt of the warrior. Just below them is a line of three fainter stars, which at this time of the year runs nearly up and down. On a clear night the central one of these three will have a slightly fuzzy appearance. In fact, it is not only a star, and a so-called triple star, but also a tremendous mass of glowing gas called a nebula. The diameter of this nebula is several million times the distance from the earth to the sun and is equal to the distance from the earth to Sirius. The

bright white star which is a little below, and somewhat to the right of the belt of Orion, is Rigel, a first-magnitude star, which in light-giving power is at least ten thousand times as great as our own sun.

To the right of the belt of Orion and somewhat above it, or at a point almost straight southwest and about halfway between the horizon and the zenith, is the great constellation Taurus. Near its center is the red star Aldebaran, which the ancients represented as the eye of the bull.

North and northwest of Aldebaran is the small group of seven strikingly arranged stars called the Pleiades. Six of the seven are of the fourth magnitude and are easily visible without optical aid. The seventh, which is at one end of the group and near the sixth one, is not readily seen.

No group of stars in all the sky has attracted so much popular attention as the seven little stars of the Pleiades nor has been involved so frequently in the classical writings of the ancients or in the stories of primitive peoples. They are the "seven sisters" of the Greeks, the "many little ones" of the ancient Babylonians, the "hen and chickens" of the people of many parts of Europe, the "little eyes" of the savage tribes of the South Pacific Islands, and the "seven brothers" of some of the tribes of the North American Indians. In November (on or about the 17th) they cross the meridian at midnight, and many primitive peoples began their year at that time. It is said that on that exact date no petition was ever presented in vain to the kings of ancient Persia. The Pleiades had an important relation to the religious ceremonies of the Aztecs of Mexico, and certain of the Australian tribes held dances in their honor.

Almost straight overhead is the constellation Auriga, the Charioteer, which contains the white first-magnitude star Capella. Capella is really a twin star, the two stars visible only in a spectroscope. Capella means "she-goat," and near it are three fainter stars which are called "the kids." This star is receding from us at the rate of twenty miles per second and will on this account eventually become dimmer. It radiates about two hundred times as much light as is given out by the sun.

359. Stars visible in April, May, and June. In May, at 8 P.M., the Big Dipper is almost exactly above the Pole Star.

The Great Bear extends north, south, and west of this group, but all except the dipper are faintly shown.

The stars of the Big Dipper constitute a great group having nearly parallel motions. In the Big Dipper the star at the head of the handle is called Mizar. It is about 7,000,000 times as far from us as the distance from the earth to the sun, and seventy-five years are required for its light to come to us. Its faintness is due to its great distance, for it radiates 115 times as much light as the sun.

In the south, a little to the west of the meridian, is the constellation Leo, the Lion. It is marked by the Sickle, the end of whose handle is the bright star Regulus, which will be seen about two thirds of the distance between the horizon and the zenith. The blade of the Sickle extends to the north of Regulus and opens to the west. Near the third star in the Sickle is a very faint one, which is a severe test for keenness of sight. One of the interesting things in connection with Leo is that it is in this part of the sky that numerous meteors are seen each year about November 14. Three times in a century this display becomes unusually magnificent.

Almost straight east, and about three fourths of the distance from the eastern horizon to the zenith, is the fine orange-colored star Arcturus, in the constellation Boötes, the Hunter. This star is so far away that a hundred years are required for its light to reach the earth. In light-giving power it is at least five hundred times as great as our sun.

360. Stars visible in July, August, and September. In August, at 8 P.M., a small but very interesting group of stars known as Lyra, the Lyre or Harp, is almost directly overhead. It contains a very brilliant bluish-white first-magnitude star called Vega.

The sun, with all its planets, is moving in the direction of Vega at the rate of about 400,000,000 miles a year, but the distance of this star is so enormous that no appreciable change in its brightness will be produced by this motion in the next ten thousand years. The exact distance of Vega from the earth is

not known, but it is thought to be more than 3,000,000 times as far as the distance from the earth to the sun. An interesting fact about Vega is that in twelve thousand years it will be our Pole Star. This does not mean that Vega will move over to the position that the Pole Star now occupies, but that the axis of the earth will change until it points in the direction of Vega. This change is produced by the attraction of the sun and moon for the equatorial bulge of the earth. Nor will Vega be permanently the Pole Star, for the position of the earth's axis changes continually, completing a circle in the heavens in about twenty-six thousand years.

Just west of Lyra is the large constellation Hercules, the Kneeling Hero. It contains no bright stars. In the south, and a little to the west of the meridian, is one of the faintest groups of stars in the whole sky. This is Scorpio, the Scorpion. It can always be recognized by its fiery-red, first-magnitude star Antares, which in light-giving power is several hundred times greater than the sun. Antares is represented in mythology as occupying the position of the heart of the great scorpion. According to a Greek legend Scorpio is the monster that killed Orion and frightened the horses of the sun so that Phaëthon was thrown from his chariot when he attempted to drive them.

PART V. THE EARTH'S SURFACE

CHAPTER XXIV

HOW ROCK BECOMES SOIL

361. Questions for discussion. 1. Sometimes in the coldest winter weather, when a bottle of milk has been left out of doors, it is found that the cover is lifted and the milk and cover stand above the top of the bottle. What lifted the cover? 2. In mountainous regions in winter, even in quiet weather, pieces from the faces of bare rocks are broken off and fall, though nobody has in any way disturbed the rock. What probably causes this to occur?

3. What will occur if a strong metal cylinder filled with water and plugged tightly is placed where the water will freeze? 4. Sometimes the bricks in the most exposed wall of a building crumble much more rapidly than those on less exposed sides. Can you account for this? 5. Explain how winter or early spring weather lifts clover or alfalfa from the ground. 6. What is a glacier? How do glaciers affect the soil of glaciated regions? 7. Is the soil of your region of glacial or of sedimentary origin? 8. How do plants and animals contribute toward breaking rocks into smaller pieces?

9. If a lot is to be secured on which to build a city home or factory, does it make any difference as to what kind of soil composes the lot? Why? 10. What kinds of soils in your community are considered the most valuable? For what purposes? 11. To what extent does the value of farm lands in your state vary according to the predominant kind of soil? 12. Are the drained lowlands more fertile than the highlands? Why?

362. Food from rocks. It is not easy to understand what would be the condition of the human race if all soil were removed from above the rocks which compose the greater part of the earth. However, just this situation did exist at one time,

and still exists in some regions of the earth's surface. No one would choose a bare rock surface as the location for his home unless provision were made for him to secure the products of regions with fertile soil. Such farming and forested regions as are shown in figure 179 are possible as homes for men because of nature's processes of changing rock into material which may



FIG. 179. Soil from rocky hills

As the rocky hillsides weather and break, the fragments accumulate in the valleys and help to produce the fertile fields

be the foundation for productive soils. A beautiful view of a farm landscape may serve not only for immediate pleasure but may also suggest that the region shown is, in fact, a summary of long ages of nature's processes. The "new lands" which the pioneers found and from much of which they had to remove primitive forests were really not new, since nature had been working for unknown ages in producing the soil upon which the forests and prairie meadows grew.

363. The surface of the earth. The floors of oceans and lakes, like the uncovered land surfaces, are undulating, so that the

water has different depths in different places. Sometimes whole mountain ranges and the intervening valleys are covered by the same body of ocean water. About three fourths of the solid surface of the earth is covered by water.

Uneven places in the uncovered land surfaces are easily noted in mountain regions. Even in most so-called level plains the surface is not really smooth. The nature of this unevenness—



FIG. 180. The "everlasting" rocks

Solid rock may always be found at a relatively short distance from the surface.

Here the layer of soil is particularly thin. (Presque Isle, Michigan)

abrupt or gentle slopes, long or short slopes, long ridges or round knolls, gulleys, etc.—gives distinctive character to a landscape and does much to determine the type of agriculture or other uses of a region.

In places the surface consists of solid rock (fig. 180), and solid rock may be found anywhere if the surface material is penetrated deeply enough. It is thought that ages ago, when the earth's surface was first exposed, the surface was all solid rock. In many places we may still see rock in its primitive stages of changing into soil. In other places we find good soil and abundant natural vegetation; in others, rich garden soil which makes our commercial gardens possible; in others, undrained swamp lands; and in still others, sand and bare rock.

364. The surface and water. If the earth's surface were perfectly level, water which falls upon it would not flow off in any definite direction. With the unevenness that exists, water runs from higher to lower levels except where absorbed and held by the surface materials. Thus, in the changes occurring upon the earth's surface, water has accumulated, making ponds in some places, lakes in others, and oceans in others. Where water runs over the surface of the earth, it follows the depressions until it finally comes to a place of so low a level that it no longer flows. When the difference in level is great enough between two places which are near one another, water runs rapidly from one to the other. If the difference is abrupt, a waterfall is formed (fig. 109). Falling water wears away the hardest rock if the falling continues long enough. Not only does the water itself wear the rock upon which it falls, but many large and small pieces of rock are carried by it, and these add greatly to its cutting power.

365. The work of freezing water. Water may readily enter crevices in the rock. When it freezes it expands, and its expansive force is very great. Alternate freezing and thawing may break the rock into smaller and smaller pieces. An interesting experiment to show the effect of freezing water may be made by filling a strong metal cylinder with water, plugging the ends of the cylinder tightly, then placing it where the water will freeze, and carefully noting the results. If it is not freezing weather a pack of cracked ice and salt will freeze the water.

Along rocky cliffs where water runs into crevices and freezes, one may often observe its effect in breaking up the rock (fig. 181). Tons of rock may be pushed aside a short distance by the expansive force exerted through the freezing of a small amount of water. When we think of all the small crevices in rock into which water may run and afterwards freeze, we may imagine the enormous amount of work that is done in breaking up rock.

366. Disintegration of rock by water. Rock often contains substances, such as lime, salt, or compounds of sulphur, which may be taken up in solution in water. If water has filtered for

a long time through rock which contains soluble substances, the rock is made porous by the removal of these substances. Great caves, such as the Mammoth Cave, Kentucky, have been made in this way. If the water is heated (as sometimes occurs within the earth's crust), or if it contains acids, its dissolving effects are much greater.

Streams and waves of water are also important factors in disorganizing rock. In streams stones are rolled, turned, and

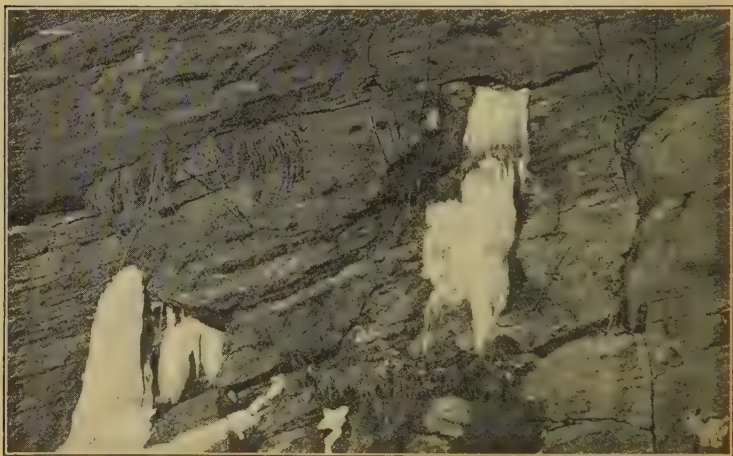


FIG. 181. Freezing water breaks the rock

Note also that last year's plants grew in crevices of the rock

ground over one another and constantly worn thereby. In swift-flowing mountain streams very large rocks are torn from their positions, rolled over and over, and often carried down to levels where the current is not so swift. From the large rocks smaller pieces are broken and are then carried downstream to places where the current is much less swift than where the larger rocks are left. From the mouth of a stream to its mountain source, soil and rock particles show the carrying and wearing power of the stream. Many of the finer rock particles may be carried by the stream until it reaches the large body of water into which

the stream empties—sometimes the ocean. When streams overflow their channels, there is an abundant deposit of fine soil particles that were carried by the water.

Along the shores of lakes and in the riffles of streams there may constantly be seen the process of wearing rocks into smaller

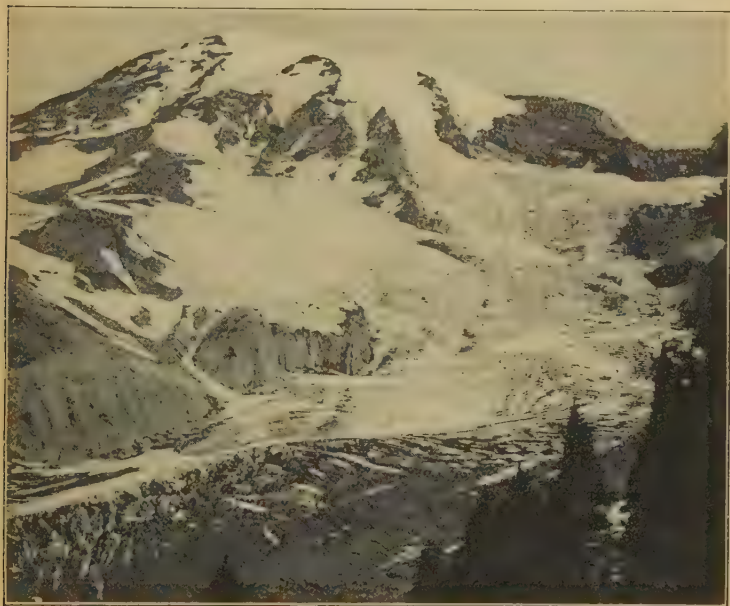


FIG. 182. A glacier valley

A glacier on the slopes of Mount Rainier, Washington. At the lower end and in some other parts the ice is carrying the broken stone which has been removed from the glacier's course. Photograph by Dr. G. E. Nichols

and smaller particles. This same action of the water also sorts the materials into the different sizes, and one may find these sizes assorted in definite regions as he passes from the shore into deep water.

367. Glaciers and the earth's crust. In former times glaciers were important agencies in changing the earth's crust, and in some places their work is still going on (fig. 182). The glaciers

have been formed by tremendous accumulations of ice, which fell as snow and then, by pressure of its own weight, became ice. Ice, like water, flows toward places of lower level, though it flows very slowly. As it moves it may grind or tear away the rocks in its path and carry the fragments along with it. Often these rocks are ground over one another, and marks or scars are



FIG. 183. The end of a glacier

The ice is covered with stones and gravel. In the foreground is an accumulation of the material which has been brought down by the glacier. Photograph by Dr. G. E. Nichols

left as evidence of their contact and the force which acted upon them. When the temperature becomes warmer or when the glacier reaches a place of warmer temperature, the ice may melt, thus leaving the rock and sand that it is carrying (fig. 183). The melting ice forms streams which, as they flow from the glacier, carry away some of the solid material.

A large part of North America (fig. 184) was once covered by glaciers, and we still have many evidences of the tremendous

effect they have had upon the surface and upon soil formation. Much of the richest soil of the central United States was brought



FIG. 184. The continental glacier

The map shows the extent of the continental glacier in North America. After the United States Geological Survey

to its present position by glaciers. A study of the maps of Illinois, Iowa, and other states will show that the soil of the so-called corn belt is of glacial origin.

368. Rock broken by plants and animals. When the roots of plants grow into crevices of rock they often exert sufficient force to split it (fig. 185). Many lowly plants, such as lichens and mosses, grow upon the surfaces of rock, and the organic prod-

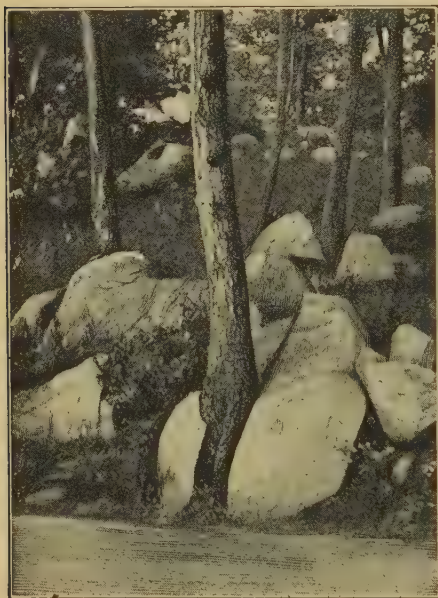


FIG. 185. Growing plants are more powerful than the rocks

This tree began as a small seedling whose roots slowly but surely broke the rock upon which the tree now partly rests

ucts (acids) formed by them assist in disintegrating the rock. When once a small amount of broken rock and organic soil material has been formed, a growing-place is thus provided for other plants and animals, which grow and in their turn make further contributions to soil-making. Unless this soil is washed away, it may constantly increase in its depth and productivity.

369. Kinds of soil.

The soil from near a lake or ocean shore is usually composed almost wholly of sand. Sometimes this sand is coarse or gritty and sometimes it is almost

as fine and smooth as flour. Near the water's edge quite coarse sand may usually be found. Back from the shore, where plants are growing abundantly, the sand is discolored and contains the substances resulting from decay of plant and animal bodies. Where decayed organic matter is very abundant the soil is called loam. In some streams of water along the riffles small stones are found in large numbers, and more or less sand is mixed with

them. This material is gravel. A soil in which such material predominates is gravelly soil. Often by digging through the surface loam or by observing a roadside bank we find a soil which is composed of very fine and compact material, so compact that when moist it may be pressed into solid balls. This is known as clay. "Silt" is the name applied to the fine, rich soil that is



FIG. 186. Peat for fuel

Vegetation deposited here for ages slowly became a semi-solid mass, useful for fuel. (Photograph from the United States Department of Agriculture)

deposited by currents of water. It is commonly deposited on broad bottom lands at times of high water. In low, swampy ground plants may grow in great quantity and fall down year after year. Their bodies partially or completely decay and become pressed into a porous soil known as peat (fig. 186).

370. Structure of the soil. If pure, coarse sand is examined under magnification, it is readily seen to consist of many small rock particles. Some are flattish, some are cubical or oblong, some have sharp corners, and some are well rounded. The surfaces of these small particles of rock are glistening and glasslike.

In fact, glass is made by melting pure sand together with other substances. An examination of sand of different degrees of coarseness readily shows that the difference is due to variation in the size of the rock particles of which the sand consists. In sand that is fine enough to be blown by the winds the particles are usually so small as to look like dust, but upon magnification their rocklike nature appears.

Clay consists chiefly of extremely small particles which fit together so as to make a compact soil—so compact that, when quite dry, pieces of this soil are sometimes said to be “as hard as rock.” A high magnification is required in order to distinguish the smallest rock particles in clay soils. Mixed with the finest clay particles we sometimes find sand, peat, or gravel, the result being sandy, peaty, or gravelly clay.

We may therefore have many gradations in soils: from finest clay to coarse clay; from finest sand to coarse sand, and on to coarse gravel and even to rocky soil; from sandy or clayey soil with but a slight amount of decayed organic matter to peat, in which there is little or no clay or sand. In nature these soils are found in all possible mixtures. A careful study of the table in section 371 will enable you to learn a good deal about how soils may be mixed and also about the size and percentages of the different parts of which they may be composed.

371. Size of soil particles. Careful measurements have been made of the actual size of the particles of different kinds of soils, also of the percentage of air space in these soils. The following table presents the data for some of the chief types of soils:

KIND OF SOIL	DIAMETER OF PARTICLES	PERCENTAGE OF PORE SPACE
	mm.	
Fine gravel	2-1	37.60
Coarse sand	1-0.5	39.88
Medium sand	0.5-0.25	34.43
Fine sand	0.25-0.10	35.32
Silt	0.05-0.005	44.15
Clay	0.005-0	52.94

CHAPTER XXV

SOIL WATER, DRAINAGE, AND IRRIGATION

372. Questions for discussion. 1. What kinds of soils are most likely to remain sticky for some time following a rain? 2. Can you determine why this is true? 3. If a piece of clay, a similar piece of black loam, and a pile of pure sand are placed upon a heavy wet blotter, will all the soils become equally moist and with equal rapidity? 4. Is a wet soil colder or warmer than a dry soil? Why? 5. How much water is used in making a ton of ordinary clover hay? 6. How much would be used in making the hay of a twenty-acre field at the average rate of acre yield in your locality?

7. To save the water supply in time of drought, is it best not to cultivate the soil? Why? 8. Why should artificial drainage be used in most soils? 9. To what extent is artificial drainage used in your locality? 10. Is there a noticeable difference in yield in artificially drained regions as compared with those not drained? 11. Where are the chief irrigation projects of the United States?

12. If there were enough water available, do you think the solution of the world's food problems might be helped materially by irrigating the arid lands of the United States? 13. Does dry farming promise large returns in production? Why? 14. Where are the chief swamp lands of your state? 15. What is being done toward reclaiming them? 16. What advantages would there be to the United States from the possession of a kind of wheat which would not be injured by drought?

373. Amount of water in the soil. It is commonly observed that coarse, gravelly soils do not hold water for a long time and that fine soils do. If a series of glass tubes are filled with soils of different degrees of coarseness, and the same amount of water is poured into each, it will be noted that less flows out from the finer soil. Why is this? Water may be held in the soil in either of two ways: it may adhere closely to the surfaces of the soil particles (fig. 187), in which case it is known as water of adhe-

sion, or it may be free between soil particles, when it is known as free water. Most of the free water may flow away if there is adequate outlet for it, but adhesion water is not easily removed.

Obviously the more surface exposed, the more water may be held by adhesion. In the finer soils much more surface is exposed than in coarse soils. This may be illustrated readily by measuring the exposed surface of a cube, then cutting the cube

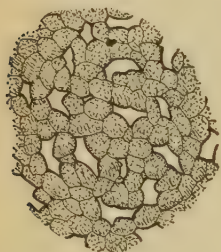


FIG. 187. Distribution of soil moisture

Diagram to represent soil particles, each covered by a film of water. In wet weather or immediately after a rain all the spaces might be filled with water

into many small cubes, measuring their surfaces, and comparing the last measurement with the first. A marble exactly 1 inch in diameter will just slip inside a cube 1 inch on each edge and will hold on its surface a film of water 3.1416 square inches in area. If, however, we reduce the diameter of the marble to one thousandth of an inch, it will require 1,000,000 of them to fill the cubic inch, and their aggregate surface area would be 3141.59 square inches. In coarse silt the surface area of the particles reaches an astonishing figure, since in 1 cubic foot of such soil the particles would have a surface area of 37,700 square feet. So large a surface area makes possible a large

water content. In some kinds of clay 100 pounds of the wet soil may contain 40 pounds of water, or 40 per cent of the whole weight. Since 1 cubic foot of clay ordinarily weighs about 80 pounds, 40 per cent of it, or 32 pounds, might be water. These facts make clear the tremendous differences in the water-holding power of soils.

374. Soil water and soil temperature. Anyone who has walked back and forth along the lake or ocean shore while in bathing has noticed differences in the temperature of the soil, and any well-trained gardener who desires to grow early spring vegetables selects what he calls a warm soil. What do these things signify? Soil which is very wet changes temperature much

more slowly than dry soil (Sect. 197). The water of the soil, being at a lower temperature than the air near the ground on a sunny spring day, makes the soil feel cold. If in the hot summer weather the soil may be cultivated in such a manner that the water will be held in it, the soil will not become so hot and will therefore be a better living place for plants.

375. Amount of water used by crops. From the calculations given it is evident that some soils may contain much water, but it is true that large amounts of water pass off from the soil by evaporation and that plants take much water from the soil. Growing plants are constantly carrying water through their roots, stems, and leaves, using some of it in food manufacture, and allowing most of it to evaporate. The following data show the average quantity of water used by three common farm crops :

Corn: 50 bushels per acre require 1,500,000 pounds of water.

Potatoes: 200 bushels per acre require 1,268,000 pounds of water.

Oats: 29 bushels per acre require 1,192,000 pounds of water.

It has been estimated that in producing a ton of clover hay, which after drying is 85 per cent dry matter, 375 tons of water are carried into the air during the growing season, either through the plant or by evaporation directly from the soil. There may often be a yield of more than 2 tons of clover hay to the acre; but, assuming it to be 2 tons, the amount of water taken from the soil to make the crop is equal to more than 6 inches of rainfall. It is estimated that water equal to a rainfall of almost 10 inches is used in producing a crop of corn of 50 bushels per acre. What amount of rainfall is there in your locality during the growing season?

376. Soil water as affected by tillage. The ways in which farm and garden soils are cultivated have much to do with their water-holding capacity. When water evaporates from the surface of compact soils, the water from below, if there is any, immediately comes to the surface. Water passes through relatively solid soils.

If an extremely fine-drawn glass tube is placed with one end in a dish of water, the water will rise some distance in the tube. This action is known as capillarity. The narrow spaces between the soil particles act as capillary tubes, and the soil water passes upward if the soil is compact enough to have the narrow spaces continuous.

The action of the soil may be illustrated by using a piece of compressed sugar. Touch one end of the lump to a liquid, and the liquid soon goes through the entire lump. This suggests the way in which, in dry weather, compact soils lose their deep soil water through capillarity and evaporation. Another experiment, with two lumps of sugar, will suggest a method of cultivating soils so as to hold moisture. Allow a second lump to lie loosely upon the first, which just touches the liquid, and the liquid will pass into the second very slowly, if at all. The so-called capillary connections within the lumps of sugar are not continuous between the two; there are no continuous lines along which the water passes. In the same way constant surface cultivation of the soil keeps the capillary spaces broken, and water does not pass upward through the soil rapidly. If the soil is deeply plowed at the beginning of the season and thoroughly cultivated on the surface throughout the season, there is (1) a reservoir for catching water and (2) a device for preventing its rapid evaporation.

377. Natural drainage of soil water. Water may be drained from soil by surface drainage or by underground drainage. Either type of drainage may take place naturally or artificially. When rains or snows leave more water on the soil than it will absorb, the water flows away toward regions of lower level. When very heavy rains fall in a short time or when snow that lies upon frozen or rocky soil thaws rapidly, the run-off may be very great. When rain falls slowly, the soil will take up an amount of water so large that if it had fallen in a brief time floods would have been produced. Surface drainage naturally results in streams of water which flow together, finally forming a large stream, which may drain by means of its

tributaries, many hundreds of thousands of square miles. A river system is a natural system of soil drainage.

Under the surface the water also flows toward a lower level, and these subterranean currents may sometimes come to the surface as springs or natural wells, or open directly into water-courses and thereafter augment the surface streams. The level at which water stands beneath the surface—the water table, as it is called (fig. 188)—varies in its depth below the surface in different regions. The deep clay and rock layers of the earth are often undulating, and the water table conforms to these

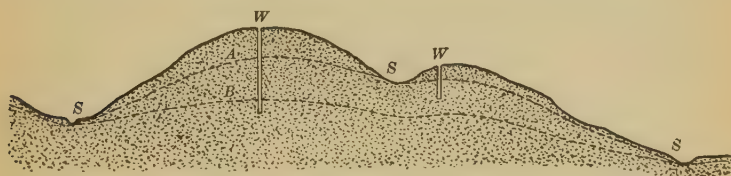


FIG. 188. The water table

Diagram to represent the water table in a series of hills and valleys. Line *A* represents the position of the water table in wet weather, and line *B*, in dry weather; *S*, springs; *W*, wells

undulations. For example, in digging a well for a domestic supply of water one farmer reached the water table and secured an abundant supply at a depth of 16 feet. Another farmer, less than half a mile away, had to dig 48 feet before he secured water. Underground water may exist in layers of rock or clay. An artesian well is secured by boring through a deep layer of dense rock through which water does not pass, into a deeper layer of porous rock containing water. The pressure from the higher portions of the same layer will cause the water to rise to the surface, and sometimes it is sufficient to cause the water to rise many feet into the air.

378. Artificial drainage of soil water. Much of the surplus water of the soil will naturally drain downward to the water table, but agricultural plants grow better when as much water is removed by artificial drainage as will readily flow into under-

ground drains. The advantages are probably at least fourfold: surplus water is removed, the soil is better aerated, the soil becomes warm earlier in the season, and injurious soil substances excreted from plant roots may be removed as the surplus water passes downward. If you will plant two jars of seedlings, one in a well-drained glass jar and the other in a jar without drainage, and give them the same amount of water, you will see some of the advantages of soil drainage.

379. Irrigation. In many parts of the country the annual rainfall is so small, or is confined to so short a period of the year, that there is not sufficient water in the soil to enable plants to grow. There are many hundred thousand acres of soil the composition of which is favorable to the growth of plants but which are deficient in water. Various devices are used for irrigating some of these lands, with different degrees of success. There are in the United States (fig. 189) over ten million acres of artificially watered lands, and projects under construction will add much to this figure. There are several methods of irrigation, but that along the banks of the Rio Grande River may serve as a type. In the lower stretches of this river the annual rainfall is quite low, but a large volume of water comes from the mountainous country hundreds of miles away in Mexico and the United States. In the lower Rio Grande valley there is much rich alluvial soil, needing only water to make it fertile. Hundreds of miles of ditches have been constructed to direct the water from the river to the land. A main canal, looking like a river, carries water in one case for more than one hundred miles. From this main canal smaller ones branch off, and finally the smallest ditches run to the individual farms. Flood-gates are used in turning water upon the fields when it is needed. In this way, with an abundant supply of water and with constant sunshine, a rapid and luxuriant growth of plants is made possible (fig. 190).

It must not be forgotten that underground drainage is advantageous for other purposes than the removal of surplus water, though at times even irrigated farms need it for that purpose

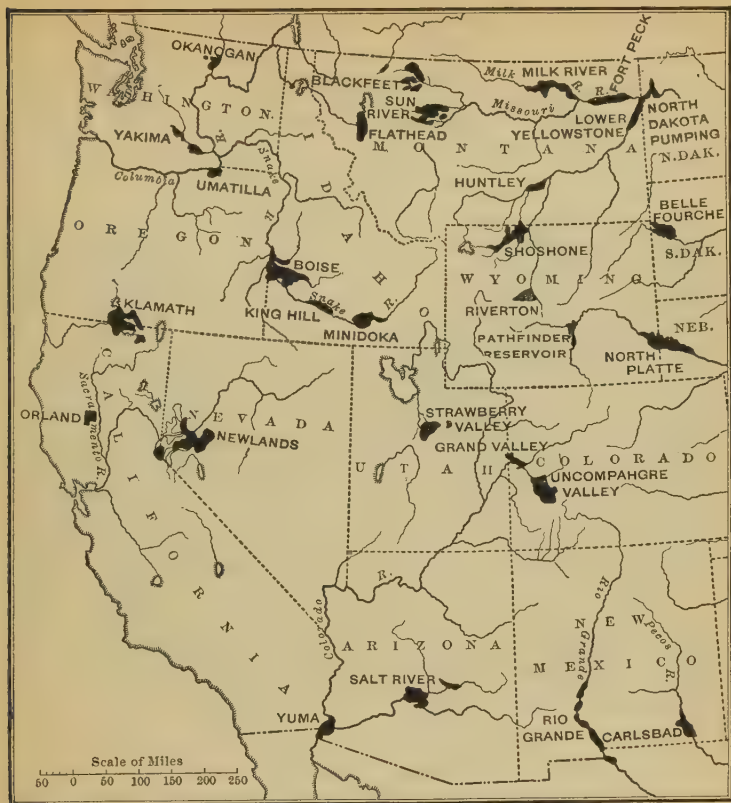


FIG. 189. Irrigation in the United States

The map shows the location of the more important government irrigation projects. There are in addition many other areas irrigated by government, private, and state enterprise. From map by the United States Reclamation Service

also. The failure to introduce underground drainage in irrigated districts is now beginning to prove a limiting factor in the production of plants, and doubtless such drainage will soon become usual there.

380. Source of water for irrigation. The larger part of our irrigation projects consists in diverting mountain streams into

valleys close by. Sometimes streams are dammed (figs. 80, p. 147, and 87, p. 156) either to assist in diverting the water or to store it for later use. Tunnels have been made through mountains, and elevated aqueducts have been built over valleys to carry these streams. In some regions irrigation by use of deep wells is practiced. Water is pumped into reservoirs, and from



FIG. 190. Irrigating an orange grove in California

In parts of California, and in other states, land having little value and producing no food, is made highly productive and valuable by means of irrigation systems. (Photograph from the United States Department of Agriculture)

these it is led off through ditches to the fields. In case of rivers which flow through flat valleys the water is sometimes pumped into irrigation ditches or into elevated reservoirs.

381. Dry farming. In some parts of the United States there is a small amount of rainfall which would give the soil sufficient water to produce a crop if evaporation could be prevented (fig. 191). In some such regions the experiment has been tried of keeping the soil under surface cultivation for a long time. First, deep plowing is done, furnishing a deep soil for the absorp-

tion of rainfall. Then constant surface cultivation retains most of the moisture, and after a time enough moisture may thus be caught and held to make it possible to grow a crop. In some places where this type of farming is done the rains are so scanty that a crop can be grown only once in two years. In these cases some water may be drawn upward from the deep soil, but most of it must come from the scanty and infrequent rains.



FIG. 191. A region for irrigation or dry farming in Arizona

This field can be made productive by irrigation or by dry-farming methods.
(Photograph from the United States Department of Agriculture)

It is evident that dry farming requires much labor in order to put the soil in proper condition for the production of a crop. Even with these difficulties fine crops have been grown by dry farming, and when we consider the extreme cheapness of land in the dry-farming regions, the relative amount of labor seems well repaid in results. Dry farming is still somewhat in the experimental stage, and whether it is to be extended to cover other large areas where there is scanty rainfall cannot be safely predicted. In any event, there are large areas of dry land which receive no rain, or practically none, and these areas must look

to some form of irrigation to make them productive. The quantity and availability of the water supply have thus far limited irrigation to relatively small areas, though the total acreage seems large. Whether the so-called Great American Desert is to disappear and become a highly fertile region is largely a question of the quantity and availability of water. There may be sources of water supply (from deep wells or from the air) not yet within the range of practicability, but these are for future developments. There is untold wealth in the soil of the arid regions for those who can put a good supply of water upon it.

382. Reclamation of swamp lands. The opposite of arid soils is found in such extensive areas as the undrained or poorly drained Everglade Swamps of Florida, the Dismal Swamp of Virginia and North Carolina, the swamps about our inland lakes (both large and small), and the overflowed areas along the lower stretches of our great rivers. The United States Geological Survey estimates that in the United States there are over 100,000,000 acres of undrained swamp land, much of which is drainable. Along the Atlantic coast alone there are estimated to be over 3,000,000 acres of drainable soil. Often this is the most productive kind of soil when it is properly drained.

In the United States large drainage systems have been built that are in a way comparable to the irrigation systems. One removes the water, the other adds it. In the Everglades of Florida thousands of acres of fertile soil have been made tillable by the construction of large drainage ditches.

As people are coming to understand better the fundamental importance of the soil in the life of all the nations, they are making constant effort to render greater areas of arid and swamp soils available for use in agriculture, horticulture, and gardening, and for homes.

CHAPTER XXVI

EROSION AND SEDIMENTATION

383. Questions for discussion. 1. Brush or old wire fences are sometimes thrown into a gully to check washing. How do they accomplish this? 2. Why are hillside farms sometimes terraced? 3. It is sometimes reported that floods have increased in number and destructiveness in the Mississippi Valley as the country has become settled and forests have been cleared away. How might removal of forests affect floods? 4. How do you account for the fact that the soil is usually more moist in forests than in adjacent fields?

5. Why is the soil of lowlands, such as bottom land along rivers, usually more fertile than upland soil? 6. Does the continual but slight loss of soil from a field represent a money loss? Why? 7. Why is it desirable to maintain trees on steep slopes? 8. May the deforestation of steep hillsides do injury to owners of other property? How?

9. What are the chief regions in your country which illustrate loss of soil by erosion? 10. What is being done to prevent this loss? 11. What efforts are being made in your state to develop a permanent forest policy? 12. Is this being done partly with reference to the state's soil or water needs, or for a supply of timber?

384. Removal of the soil—erosion. When the formation of soils was being discussed we spoke of the action of water upon rocks, gravel, and sand. We have but to look at a mountain stream or river (fig. 192) or the water running in a gutter to get an idea of the power of water to carry soil. A study of a surface stream that is flowing from a field or garden will tell a good many things about erosion. First, the heaviest particles of soil that are moved are carried only by the strongest part of the current. This part of the current may also carry all finer grades of soil material, but the slowest part of the current may be so very slow as to carry only the first particles. If a dam is

made across a very small stream, the heaviest materials are dropped where the current is first slackened, but some very fine material may not be dropped for a long time. If a drinking-glass of muddy water is allowed to stand, an estimate may be made of the time required for all the silt to settle to the bottom of the tumbler. If the water had been running, it would have carried the silt longer than when quiet, as in the drinking-glass.



FIG. 192. Erosion by a mountain stream

A swiftly flowing stream wears down its bed rapidly and forms a steep-walled valley

If one digs up two squares of soil of similar size,—one bare and the other of turf,—and both are then subjected to a stream of water from a hose, it will be seen that the turf withstands the running water much longer than does the bare soil. Erosion takes place less rapidly when soil is covered or when it is held by plant roots.

In wooded regions, where there is much undergrowth and humus, the water from rain flows from the surface very slowly. In an open field the same rain will produce a considerable

stream. The stream upon the field is soon gone, and the surface becomes relatively dry. In the woods no stream appears for quite a time, and then it is small, but it lasts for a much longer time than that in the open field; when it stops flowing, the soil of the woods is still very moist. The trees and undergrowth retard the falling rain. Humus acts as a sponge in holding large quantities of water, so that streams start slowly; and when they do start, the leaves, twigs, and bushes retard the movement so that the ability of the water to remove soil and to carry it is reduced (fig. 193). Humus retains much of the moisture after the stream has stopped flowing. Furthermore, the covering of trees tends to reduce the loss of water by evaporation.

385. Loss from water erosion. The damage done to farming soils by erosion is very great. The soil is carried away, the fields are cut into deep gullies, and

often the owner of the land realizes too late that the best part of his soil has passed entirely beyond his control (figs. 194 and 195). Obviously regions with hilly topography are more subject to erosion than are level fields (fig. 196). Such fields will lose less soil if they are kept in pasture, in meadow, or in timber. In some places, where hilly land must be cultivated, it is ter-

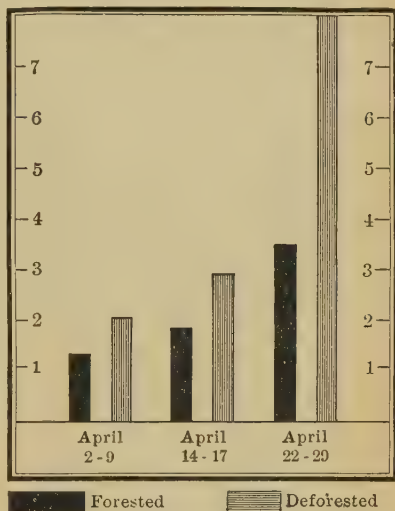


FIG. 193. Effects of forests upon drainage

Diagram to represent run-off from two similar areas in the White Mountains, one of which has been deforested. The vertical bars represent in inches the proportionate run-off. Note that the forested area retains the large amount of water. From data by the United States Geological Survey

raced around the hills, in order to prevent erosion or to catch any soil that may be moved by water.

The great importance of erosion of soils is suggested by the fact that the Mississippi River is estimated to carry over 1,000,000 tons of sediment into the Gulf of Mexico every day, or over 400,000,000 tons per year. Professor Salisbury says: "It would take nearly 900 trains of 50 cars each, each car carrying 25 tons, to carry an equal amount of sand and mud to the Gulf. All the rivers of the earth together are perhaps carrying to the sea forty times as much as the Mississippi."

386. Vegetation and erosion. When visiting the banks of a stream which has recently overflowed we usually find silt or mud deposited upon the plants along the banks. The more dense the vegetation, the larger the quantity of silt deposited. In many overflowed regions deep layers of rich soil have been built up through periodic deposits made in this way (fig. 196). Where the water of the stream is flowing rapidly, it can carry its load of silt, but when its rate of flow is reduced, it drops part of its load.

Not only does vegetation exert a strong influence upon the deposit of silt but it also helps to prevent erosion. The parts of plants above the soil retard the flow of water, and the roots within the soil help to prevent the removal of soil. In many places one may see instances in which water has been turned aside and the soil left where plant roots were well established. One of the most effective ways of preventing erosion along hill-sides and stream banks is by introducing rapidly growing plants which help to hold the soil.

387. Deposit of soil from erosion. It is estimated that at least one third of the sediment carried by streams of water reaches the sea. The other two thirds is deposited in various places as gravel, sand, and silt. In times of overflow of the channel banks this deposit is large, but we must remember that erosion is also great at such times. When streams overflow, the velocity of the water is usually decreased and much of the load of soil is dropped. In this way large areas along the Mississippi



FIG. 194. The right way



FIG. 195. The wrong way

The upper figure shows a Southern pine forest properly used, and its vegetation protected. The lower figure shows the same kind of region, all timber removed and soil washing away. Photograph by the United States Forest Service

River are annually replenished by the richest soil (fig. 197). Great dangers attend such overflow, however, and an effort is being made to prevent it by building strong dikes in the attempt to hold the river within its channel.

At the mouth of such great rivers as the Mississippi and the Yangtze the accumulation of sediment has built up great deltas.



FIG. 196. A late stage in erosion

The gullies have broadened until the whole of the original surface has been removed excepting where vegetation has protected it. Photograph by the United States Forest Service

Much of the tremendous quantity of soil thus carried into the sea goes far from shore and doubtless sooner or later settles to the bottom to contribute its part in filling the ocean basins. Since this sediment has been eroded from the highland areas, it is evident that its removal from one place and deposition in another contributes slowly but surely to the processes of leveling the earth's surface.

In China some of the people near the mouth of the Yangtze River flood their fields at a time when the river is heavily laden

with silt, in order to replenish their soil. Untold wealth in soil is constantly being lost to the human race through erosion, and the problem of maintaining the fertility of the soil is annually made more difficult thereby.

388. Erosion by wind. We have but to recall the dust clouds of windy days to see clearly that the air has a soil-carrying

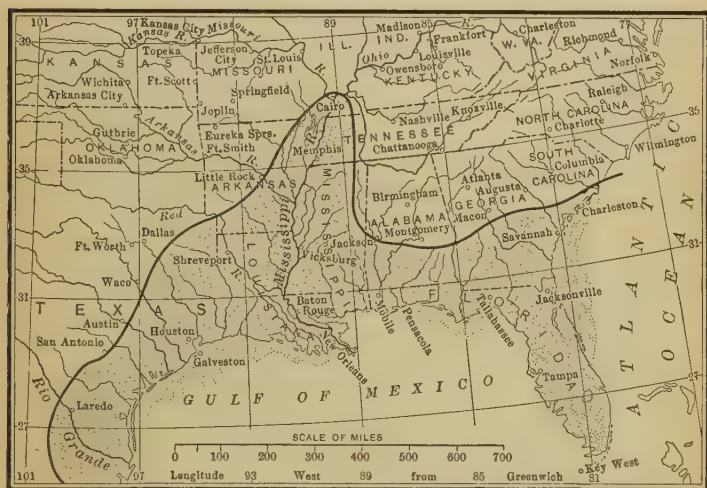


FIG. 197. Deposit of soil by rivers

The shaded portion in prehistoric times was a part of the Gulf of Mexico, but has been made into rich lands chiefly by deposit of material carried down by the rivers. Redrawn from *Popular Science Monthly*

power, and if we will keep a moistened surface, such as that of a glass or a towel, in the dust-laden air for a few minutes we shall be able to get some notion of the quantity of this dust. Snow soon becomes colored by dust carried by the wind from places where the soil is exposed. The air is never entirely free from dust. This air-borne dust is deposited everywhere and in some places has accumulated in immense banks known as loess.

Sand is carried by air currents, and, as in the case of water, the strongest currents carry the largest pieces. Along the shores

of lakes and oceans the action of wind-blown sand is readily seen (fig. 198). Sometimes it cuts the bark from trees and carves out the softer portions of large rocks. The finest sand may be carried great distances.

In some regions the winds build dunes, or hills, of sand. Some of these dunes may keep moving inland as sand from the



FIG. 198. Erosion by wind

The hill to the right, a sand dune, is being blown away in spite of the protecting cover of vegetation. At the left, sand is burying a group of trees

windward side is carried over and dropped on the leeward side. A dune may thus migrate far inland, burying everything in its path. With a change of prevailing winds it may migrate back to the shore or even into the lake or ocean. Sometimes grasses gain a foothold on a dune and their fibrous roots hinder the sand from blowing. The grasses are often followed by trees, and the forest may live upon a dune for ages. Afterward, winds may again bring sand to the dune, cover the vegetation beyond the tops of the tallest trees, and later uncover all and even remove the dune upon which they stood.

In some of our Western states, Kansas and Nebraska for instance, there are wide stretches of sandy soil which in some places form dunes. On some of the cultivated land great annoyance is caused by removal of the soil by winds when it is freshly plowed. At such times the soil may drift along fence rows much as snow drifts in winter. *American Forestry* says:

When the soil is broken, the soil blows so badly that hundreds of "nesters" who have tried to make a start in this region have moved out only when their fields have blown into the next section or county. On a bright day in spring in the sandhill section of Kansas, with what is known in that country as only a brisk wind, it is possible to locate all the plowed land for from fifteen to twenty miles around by the dense clouds of sand that stand out against the blue heavens like pillars of gray smoke.

CHAPTER XXVII

LIFE IN THE SOIL

389. Questions for discussion. 1. Prepare a list of the living things which you know make their homes in the soil. 2. What is the relation of plant lice, or aphides, to the growth of a crop of corn? of ants to aphides? of the bird known as the flicker to the ants? Is the destruction of the flicker helpful or harmful to agriculture?

3. How do bacteria affect the supply of nitrogen in soils? 4. Why is it that nitrogen-producing bacteria are not present in some old soils? 5. Why are bacteria necessary to the best growth of clover, alfalfa, and cowpeas? 6. From your state agricultural experiment station get a bulletin which tells you the best ways to plant clover, alfalfa, and cowpeas so as to insure the presence of the proper bacteria. Make a class report upon this topic. 7. What is the chief bacteria-using crop in your country? 8. How long has this crop been extensively grown? 9. Are most farmers successful with it?

10. In what ways do plants and animals contribute to the development of soils in uncultivated areas? Can you prove that plants help to form soils? 11. How do earthworms contribute to enrichment of soils?

390. Plants and animals as soil-formers. In sand upon which plants have grown for a few years a careful study will usually show, in addition to the sand, some of the remains of plant roots, stems, or leaves. The older remains of plants may have decayed to an extent that makes it difficult to recognize their origin. Although rock particles are the basis of most soils, these particles alone would furnish little support for plant and animal life.

When peat is examined under magnification little or no sand is seen, but this soil consists almost wholly of the more or less disorganized particles resulting from dead plant and animal bodies. Peat is so nearly pure plant material that when dry it makes a fairly good fuel. In some parts of the world it is cut

from the earth in brick form, dried, and then sold in the markets (fig. 186). Sometimes peat soils catch fire and burn slowly for weeks or even months.

In deep woods we have another illustration of the deposit of plant material in large amounts. Leaves, twigs, and stems of plants fall and decay, thus forming a layer rich in humus in which luxuriant growths of plants are found. To be fertile all soils must have some humus in them. One of the great problems of modern agriculture is to supply by natural or artificial means the organic matter that is necessary for proper growth of plants.

391. Living things in the soil. There are also living things in the soil, chiefly microscopic, which are of very great importance. There are fairly large animals like foxes, woodchucks, and minks, which burrow in the ground. The ground has also many small animals, for example, the earthworms, the larvæ of many kinds of insects, many adult insects, and many microscopic animals. In addition to the roots of plants there are many kinds of lower microscopic plants, chief of which are the bacteria. These animals and plants live in whole or in part upon organic and mineral matter in the soil, and not only through their life processes but also by the decay of their dead bodies they contribute to the organic matter in the soil.

The influence of earthworms in soil formation is often very large. They eat their way through the soil, thus making burrows. In their bodies digestive fluids are added to the soil that has been eaten, and when this is expelled from their bodies the soil is changed so that its fertility is increased. The burrows of the earthworm provide added opportunity for air to enter the soil, which is a matter of much importance. A garden with many earthworms in it is likely to be a rich garden.

The soil must not be looked at as merely a dead mass of mineral particles derived from the disintegration of rock. It is that and much more. It is inhabited by a multitude of living things. The different organisms living in the soil may prey upon one another quite as do those that live aboveground.

392. Interrelationship of living things in the soil. The extent to which interrelations may go is seen in the relationship between the roots of the corn plant and certain animals that may often be found upon or near these roots. Extremely small insects, known as plant lice, or aphides, bite into the tender roots of the corn and suck out the nourishing juices. The aphides are almost stationary animals and cannot ordinarily make their way from one plant to another without assistance. When well nourished they excrete small drops of a glistening, sweetish solution sometimes called honeydew. This honeydew is an article of food for certain black ants which also live in the cornfields. It has been found that the ants will dig furrows down at the side of the corn plants until they can reach the roots, and will then carry the aphides and place them upon younger and more tender roots. When food for the aphides becomes scanty, they are moved by the ants to new plants. The aphides thus secure abundant food, and the ants secure the honeydew as their own food. Both are parasites upon corn, one directly, the other indirectly. Corn and grass are often killed by these animals, and the soil, rendered porous by the burrows, dries more rapidly than it otherwise would. This is but one of many illustrations of the interrelationship of animals and plants in the soil.

393. Raw materials for plant food. The most important elements that plants need in order to grow well are carbon, oxygen, hydrogen, nitrogen, iron, phosphorus, and potassium. The carbon is obtained from the air, for ordinary air contains about three parts of carbon dioxide in ten thousand parts of air. All the other elements are secured from the soil, where they appear in various combinations. Obviously a soil is fertile that has an abundance of the needed substances and that does not hold other injurious substances, such as plant poisons, which sometimes exist in the soil. Very little is known about plant poisons in the soil, but recent investigations show that some plants excrete substances which may be injurious to them and possibly to other plants.

Water is one of the most important substances of the soil. Plants use water directly as a raw material for food manufacture, and they also use other materials which are secured from the soil only when they are dissolved in water. If water were absent from the soil, plants would starve; and if there is too much water, some plants will drown from lack of air.

394. Loss of nitrogen from soil. Where the soil is covered with a growth of native wild plants, it is not probable that as the years proceed there is any decrease in the amount of nitrogen compounds in the soil. The nitrogen compounds are absorbed from the soil by the roots of plants, but they remain in the plants, and when these die and decay the greater part of the compounds are returned to the soil. On cultivated ground the case is quite different. There the whole plant or a part of it is harvested and taken away, and the nitrogen which the removed part contains in the form of protein and other compounds usually does not return to the soil. In a grain of wheat there is 12.2 per cent of protein, of which a large part is nitrogen. It is calculated that in reaping a crop of twenty bushels of wheat from an acre the farmer is removing twenty-five pounds of nitrogen; at that rate there would be a deficiency of nitrogen compounds in a few years unless the loss could be replaced in some way.

We have spoken of the loss of nitrogen only. It is thought that other necessary minerals are exhausted in a similar manner.

395. The supply of nitrogen. It is a common practice to return to the soil, in the form of manures, as much as possible of the straw and other materials which have come from the fields. In this way much may be done to maintain the fertility of the soil. There is always a loss, however, in the grains and other materials sold and taken off the farm. There are certain other unavoidable losses of nitrogen compounds through processes of decay and in streams of water.

396. Bacteria and nitrogen. There are many kinds of bacteria in most soils, and they affect it in a number of ways. Some of them live upon the dead bodies of plants and animals, and in

so doing decompose them, thus adding their material to the soil. Bacteria and small animals are highly important as instruments of decay. By their action the nitrogen-containing dead bodies are changed so that the nitrogen compounds may again be used by growing plants.

There is another group of soil bacteria of peculiarly striking interest. These are often found growing in great numbers in little nodules (or tubercles, as they are called) on the roots of clover, beans, peas, and other plants that are related to these. It has also been found that these tubercle bacteria are able to use nitrogen from the air of the soil and combine it with oxygen in such a way that higher plants, such as corn, wheat, and oats, can then use it. One of the greatest problems in maintaining desirable fertility of soils consists in keeping the proper supply of nitrogen compounds. Plants other than these bacteria cannot ordinarily use the free nitrogen of the air, but the tubercle bacteria can do so and thus make it available to other plants. Plants such as clover, peas, etc. do not grow so well when bacteria are not present on their roots, and the compounds of nitrogen that are needed for subsequent crops are not deposited in the soil. It is common to restore the nitrogen supply of land by planting it to crops of clover, alfalfa, cowpeas, or other related plants.

397. Protozoa in the soil. It is only in late years that something has been learned about the protozoa, or one-celled animals, in the soil, and our knowledge is still very limited. It is now believed that they feed upon the bacteria, and that under some conditions they may destroy the bacteria to such extent that the enrichment of the soil by the action of bacteria as described above does not go on satisfactorily.

398. Commercial nitrogen. If the use of these plants and their bacteria does not restore the land, it is possible to scatter over it certain nitrogen-containing materials. Nitrogen and other important plant foods are secured in large quantities from tankage, dried blood, etc., produced by the meat-packing houses and from ammonium sulphate, which is produced in the coke

ovens. Another substance commonly used is a nitrate called Chile saltpeter, which is mined in great quantities in Chile and exported by shiploads. Important processes have been discovered by means of which the nitrogen of the air can be secured and used for agricultural and other purposes. Large factories have been constructed for the purpose of preparing commercial supplies of nitrogen compounds by use of nitrogen from the air.

399. The soil and its significance. The soil is the natural growing place of most plants and of many animals. The roots of plants are usually embedded in the soil. The stem is also underground in many cases, as is true of the dandelion, plantain, parsnip, and radish. Plant roots spread more or less in the soil, sometimes many feet from the rest of the plant, and may also descend to considerable depths. From the soil these roots secure various substances. The soil not only serves as a source of supply of food materials but also gives anchorage to the plants whose roots are embedded in it. Many animals also live in the soil, and all of them are dependent directly or indirectly upon the plants that grow within or upon the soil. Animals such as the earthworm, the gopher, the fox, and the groundhog burrow in the soil and thereby secure food in the form of plant roots or decaying organic matter, or secure homes that furnish them a measure of protection from enemies or from extremes of temperature.

Among human beings it is not the farmer alone who is interested in the soil, for upon its fertility depends the production of foodstuffs for all of us. If it is generally lacking in the substances and conditions necessary for plant growth, there will not be enough food produced to supply the needs of the country, and all will suffer either in the prices paid or because of the lack of food.

In this country our ancestors had a rich, unused soil when agriculture began. It was so rich that they thought it quite inexhaustible. Already, in the parts of the United States that have been longest cultivated, soil has become so unproductive that in some cases it is worth little.

PART VI. LIFE UPON THE EARTH

CHAPTER XXVIII

THE PLANT COVERING OF THE EARTH

400. Questions for discussion. 1. What native plants were most common in your region before men began cultivating the soil? 2. How much of this native plant life now remains? Was it right to remove it? 3. If you have swamp lands, dry and hilly regions, and regions of medium conditions in your community, state what characteristic differences there are in these three types of regions. 4. What makes the differences in plant life?

5. Can you prove that plants and erosion are gradually filling the lakes and swamps and might eventually make them into tillable fields? 6. What wild plants growing in your neighborhood are of value? 7. Secure, if possible, the value or amount of the principal plant crops of your community. 8. What industries in cities near you depend mainly upon plants for their existence?

9. Would it be wise to allow the original native plant growth to remain in good agricultural land? 10. Are there any areas in your community which might have been more valuable if left covered by native vegetation? Why? 11. Why are plants killed when salt brine is poured upon their roots? 12. Explain what occurs when dried raisins or prunes placed in a dish of water soon become plump in form.

401. Abundance of plants. Almost everywhere the surface of the land is covered with plants, if they have not been removed by man; and even where this has been done, man has usually introduced other plants to take the place of those he has removed. In countries with abundant rainfall they hide the earth so completely that the landscape is almost wholly green. Even in the deserts there are ordinarily few large areas without plants to give relief and tone to the landscape (fig. 191). A careful inspection will show that the so-called

"bare" rocks of either dry or moist countries are usually partly covered with the plants called lichens. There are plants on the mountains close to perpetual snow. Plants are found in great abundance in the waters of the ocean. (The only land areas of considerable extent which appear to be almost wholly without plants are the interior of Greenland and the region about the south pole, and these are covered with ice. Even here the surface of the snow may be colored by a minute red plant commonly known as "red snow." Arctic explorers report plants as thriving much farther northward and southward than was formerly thought to be true.

402. Variety among plant formations. The plant covering of the earth varies greatly in different regions. Each kind of plant needs for its growth certain conditions that may be partly or entirely different from the conditions demanded by other plants. For this reason any place in which the soil, moisture, temperature, and other conditions are favorable to one or a few kinds of plants is likely to be an unfavorable place for certain other plants. Thus the hilltop, which affords just the right conditions for the growth of oak and hickory trees, is not equally favorable to the growth of cottonwood or willow, and these are not usually found there. Plants which can find suitable conditions for their growth at the same place are likely to be found growing together. A group of plants which are commonly associated in this way is known as a plant association or plant society (fig. 199). There are many kinds of plant associations, and these constitute an important subject of study. (Plant associations in which trees form the most conspicuous part are known as forests.)

403. Importance of forests. From the beginning of the history of our country forests have been important. At first they were an obstacle to settlement. (They had to be cleared from the land before crops could be raised, and they sheltered savage beasts and hostile Indians.) Therefore the early settlers cut and burned the forests to the extent of their ability, but at the same time they secured from them nuts, fruits, and game for their food and the wood to build their homes and implements.

When the pioneers cut down and burned the timber which they found on the land, they looked upon the forests as inexhaustible, but this has proved not to be the case. We have cut the forests so rapidly that the eastern part of the United States produces less wood than it uses and is now securing part of its lumber from the Pacific coast. Even that large source of supply



FIG. 199. Plant associations on the margin of a pond

Note the rushes in the water, the low-shrub and tall-shrub associations beyond, and the tree association in the background

is being rapidly reduced. We ought, therefore, to be very much more careful about cutting and destroying our forests.

Forests are useful to us in many ways, the most obvious of which is for the wood which they produce. (We use great quantities of wood for fuel, for building-materials, for furniture and agricultural implements, for telegraph and telephone poles, for railroad ties, for paper, and for many other purposes) With the increasing scarcity of wood we are in many cases substituting other materials for it, but nothing else is wholly satisfactory,

and it is difficult to see how we would get on without using a great deal of wood. Indeed, in spite of the substitution of concrete, iron, and other materials for wood, the demand for it increases each year. It seems necessary, therefore, to make an effort to increase the production of wood in our country.

(The importance of forests in preventing erosion of soil and in regulating the flow of streams has been discussed in a previous chapter (Chapter XXVI))

404. Increasing forest production. In order that in the future there may be a plentiful supply of wood for all uses, it is necessary that a considerable part of the area of the United States shall be kept in forest. Of course land that is suitable for agriculture will in most cases be of greater value when it is farmed than when it grows only trees. There are many thousands of square miles of country in the United States that are so hilly or rocky that they cannot be farmed. Many of these areas were originally covered with forests, and they ought to be preserved as forest areas. They should be cared for by the state or national government in such manner as to secure the largest possible crop of forest products.

As a nation we have been very careless in the use of the forests. When the trees have been cut, only the best parts have been taken to the sawmill, and the remainder has been left on the ground to rot or burn. Usually within a year or two after cutting was done in a forest, fire would be started in some manner, and the cut-over lands would be burned. By this means the young trees that had not been cut were destroyed. After a fire the new trees that first come up are usually of the poorer kinds, and it is only as they die out that the more valuable timber trees get a start.

If the young trees in a forest are protected when the mature trees are cut for lumber, and if fire is kept out (fig. 200), the young trees will grow rapidly, and before many years another crop may be harvested. If fires are allowed to follow the logging, everything will be destroyed, and it may be centuries before a new forest is ready for cutting. All good citizens will

coöperate to prevent fires in forested or cut-over lands. About 99 per cent of forest fires are due to carelessness.

405. National and state forests. In order to be able to regulate the cutting of timber, to prevent fires, and to give the woodland proper care, the national government has retained large forest areas on public lands in the West, known as the National



FIG. 200. A young forest in Georgia

The mature timber has been removed, the brush has been piled ready for careful burning, and the young trees are left with space in which to grow. Photograph by the United States Forest Service

Forests. Under the present plan of management these areas will continue as forests perpetually and will continue to supply successive crops of wood. They are used also for grazing, as game preserves, as recreation areas, and for the protection of water supplies. Small areas have also been secured by the nation in the Appalachian Mountain region.

Many of the states in the eastern part of the United States have established state forests. These are usually on neglected

cut-over land on which the states are attempting to reestablish forest growth. It is to be hoped that in time all the areas that are more suitable for forests than for other purposes will be included in national, state, or municipal forests or carefully cared for in private hands.

406. Grasslands. The grasslands in their natural condition are useful mainly for grazing (fig. 201). In the last century a large part of the meat supply of this country came from the



FIG. 201. Grazing country

In some regions stock-raising is almost the only industry. The land may be more valuable for this purpose than for any other, especially where it is hilly or stony. Photograph by the United States Department of Agriculture

cattle raised on the great ranches which formerly occupied the Western prairies and plains. A large part of these grasslands is so level and easily tilled that it has been transformed into farms wherever there is sufficient rainfall or a supply of water for irrigation. The land is more valuable for farming than it is for grazing. There are great areas of arid lands in the West which can scarcely be used for anything but grazing except when irrigation is practicable, and these areas, together with the National Forests, will furnish a great deal of pasture.

407. Cultivated plants. Where the natural plants have been removed, it has usually been done in order to substitute for them our cultivated plants, for these supply products which we

need for food, clothing, and other uses. There is no industry in all the world so important as farming. Its products are of more value than those of any other industry, and all industries depend upon it for their prosperity. Where agriculture thrives it makes a need for transportation facilities; on the other hand, many fertile regions have had their production stimulated through the introduction of railways, since without railways farm products find only a local market. In similar ways the other industries of the entire country are related to agriculture. *Q m*

408. Plants and soil. In the chapters on soils we had frequent occasion to refer to the close relation existing between plants and the water content of soils. If we were to cut off the stem of some vigorously growing plant close to the ground, we should find that the sap would appear from the cut end of the remaining stub. A maple tree or a grapevine will show this escape of sap, or "bleeding," particularly well if a branch is cut off early in the spring. Maple trees are often tapped for the sap, which is evaporated to secure the sugar which it contains, a single tree sometimes supplying from thirty to fifty gallons of sap in one season.

It is not at all difficult to prepare an experiment which will show that water is lost by the soil when a plant is growing in it. If a pot with a growing plant is wrapped in a sheet of rubber so that no water can escape excepting from the plant, it will be found that the soil becomes drier and that weight is lost. A similar pot of soil without a plant in it and completely inclosed in rubber does not lose in weight. We should conclude that

the plant must have been taking up water from the soil about as rapidly as it evaporated from the leaves.

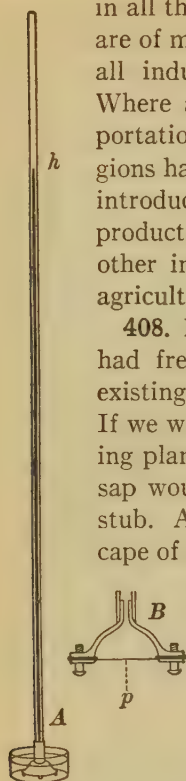


FIG. 202. A simple osmometer

A, osmometer, with the liquid in it standing at the height *h*; *B*, sectional view of osmometer, showing permeable partition *p*

409. **How plants secure water.** The first question is, How does the water get into the roots? In order to answer this we shall have to study the behavior of solutions. This may be shown by the use of a dense sugar solution and pure water. A funnel which has been filled with the sugar solution and over the large end of which a piece of parchment paper has been fastened is inverted in a dish of water (fig. 202). Since the parchment paper is permeable to water, it might be supposed that the liquid in the funnel and the water outside would come to rest at the same level. This does not occur excepting possibly for a very brief period. The sugar solution increases in volume, and the level of the liquid in the funnel rises until it overflows the top of the tube. If a longer tube were attached, the liquid might rise in it to a height of many feet unless the pressure due to the height of the column caused the paper to break.

Careful measurements of the water outside the funnel show that it decreases in volume just as much as the sugar solution increases. This means that water has gone through the paper into the sugar solution, although the pressure due to its height in the tube opposed the entrance of the water. At first but a little of the sugar finds its way out through the paper, as may be determined by tasting the outer solution. If there had been some sugar in the outer vessel of the water, but a smaller proportion than within the funnel, we should still have had the same kind of result, but the more nearly the solutions on the two sides of the membrane, or partition, are alike in the amount of dissolved matter, the less will be the difference in pressure.

It is clear that the water passes through the partition and dilutes the denser solution, thus increasing its volume. Later the solutions have interchanged until they are very nearly if not quite alike. The membrane is said to be semi-permeable, because the water will pass through freely, but the sugar will not pass so readily. The same results may be secured with other solutions and other membranes. This process by which water or other liquids may pass through a semi-permeable membrane between a weaker and a stronger solution, and by which the

volume of the latter is increased, is called osmosis. The similarity of the results of this experiment with osmosis to the results of root absorption is striking.

410. Root structure. When the tip of a root is examined, it is found to be composed of cells, as is any other part of a plant or animal. These cells resemble those seen in the leaf. They

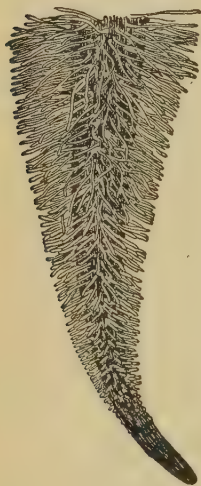


FIG. 203. A root tip

The tip of a clover root covered with root hairs. Very much magnified

are thin-walled, and it is possible for water to pass in through the cell walls. The interior of the cell wall is lined with a layer of living substance (protoplasm), with a space in the center which contains cell sap. Cell sap consists of water and some substances (often including considerable sugar) in solution. This layer of protoplasm permits water to pass inward, but it does not readily permit the sugar and most other substances which are dissolved in the cell sap to pass outward.

Each cell of the root is, in fact, an osmotic apparatus in which the protoplasm acts as a semi-permeable membrane, the cell sap being the more concentrated solution and the soil water the weaker one. If in our experiment we have used soil water and concentrated plant sap as the two liquids, we should have been imitating the plant. Of course, if the soil water should be a more concentrated solution than the plant sap, water would be drawn out of the plant, and it would die. This is what happens if a strong solution of salt is poured on the grass of the lawn.

The water which is taken in by the cells of the surface is passed from cell to cell farther into the root by osmosis and finally reaches the tubes or pores through which it is carried into the stem and leaves.

411. Root surface. Since water is absorbed only through the surface of roots, it follows that the rate at which it will be taken

up will be affected by the amount of absorbing surface possessed by the roots. The amount of surface on each rootlet is very small, for only the part within a very few inches of the tip is permeable to water. The older and larger parts of the root are covered by a bark, or corklike layer, which is almost waterproof. Extensive branching of the roots and the presence of root hairs increase the surface of root exposure.

The root hairs are hair-like projections (fig. 203) which grow out from the surface of the youngest rootlets to a length of an eighth of an inch in some cases, clothing the end of the root in a "fuzz." They are not found at the extreme tips of the roots, but the zone covered by them begins about an eighth or a quarter of an inch from the tip and extends back as much as an inch or more. Each hair is merely a tubelike extension of a cell upon the surface of the root (fig. 204), and it is able to absorb water



FIG. 204. Root hairs

These hairs add very much to the absorbing surface and assist in anchoring the root in the soil. Highly magnified

just as the remainder of the cell does. A root hair usually has many times as much surface as the cell from which it grows, and the surface of the root is increased in this way. A single root hair is very small, but there are thousands of them on even a very short piece of root. As many as 1314 have been counted on one one-hundredth square inch of the surface of a pea root. They extend into the soil, from which they absorb water and in which they help to anchor the plant firmly.

The number of root tips in a single plant is ordinarily very great. We commonly judge the root system by what we see when a plant is pulled out of the ground, but usually much the



FIG. 205. Ascent of water

Longitudinal section of a stem showing route of ascent of water; *b*, bark; *s*, sapwood; *h*, heartwood; *p*, pith. Water ascends principally through the sapwood

larger part of the root system is broken off and left in the ground. The roots of a tree ordinarily spread much farther underground than its branches do aboveground. Not only do the roots spread widely, but by repeated branching they are divided into thousands of small rootlets, which penetrate so thoroughly to all parts of the soil that it is often difficult to find under a tree a cubic centimeter of soil that does not contain rootlets. It is these small rootlets that bear the root hairs.

It must not be supposed that root hairs are roots. The hairs never become roots; on the contrary, as the root tip grows out farther the old root hairs die and new ones are formed on the newer parts of the rootlet.

412. Water-carrying tissues.

We have already spoken of the way in which water passes from cell to cell in the tip of the rootlet and of the way in which it is transferred from the

surface to the interior of the root. In some of the smaller plants, such as the mosses, water passes through the plant directly, but in all the larger plants there is a more intricate system by means

of which it is carried. The structure of the water-carrying parts is so similar in roots and stems that we shall use a stem for our example. If we cut from any of our common trees a stem with leaves and stand it with the end in red ink for a while, we shall find that the ink has ascended the stem as water would have done and has left a red stain which marks its path (fig. 205). This red stain is found only in that part of the wood which is near the bark. This means that water moves up the stem or root in the wood known as the sapwood, which lies next the bark.

Closer examination of the wood will show that it contains numerous large pores, and it is through these that water travels upward. These pores may easily be seen in oak wood. The cause of the rise of water in the stems of plants is not wholly understood.

413. Root surface and transplanting. It is ordinarily impossible to remove plants from one place in the soil to another without causing serious disturbances to the root system (fig. 206). Many of the root hairs and small roots are broken



FIG. 206. Transplanting a large tree

Note how the soil and roots are protected, so that when the tree is planted its roots will be able readily to gain anchorage and supply the rest of the tree with soil water. Photograph by *American Forestry*

off, as is usually true of parts of the larger roots. This means that in the new location there will at first be less absorbing surface than the plant previously possessed. Usually some of the roots become dry through exposure to the air and are of no use to the plant, thus further reducing the absorbing surface.

In transplanting, the branches and leaves do not necessarily suffer the same sort of reduction as the roots do. Since water continues to evaporate from the leaves, and since the absorbing surface of the roots is reduced, it is necessary to reduce the evaporating surface of the leaves by pruning. In this way the remaining leaf surface should not make too great a tax upon the absorbing power of the plants before new roots and root hairs are developed. House plants, garden plants, and those of the orchard would be much better cared for if all people would study the needs of plants when they are being transplanted.

CHAPTER XXIX

FEEDING PLANTS

414. Questions for discussion. 1. What is meant when we say a modern field of wheat, corn, or oats is man's device for exposing chlorophyll to the light so as to make it do what he wants it to do? 2. Is there the same meaning in a field of cotton? 3. In what sense is chlorophyll sometimes properly called the magician food-maker of the world?

4. When chinch bugs, grasshoppers, or crickets strip the leaves from wheat or oats the desired grain is not produced, no matter how favorable the soil and weather. Why? 5. Is it a public as well as an individual matter for a farmer to allow his farm to become poor in its production of crops? 6. How are domestic animals dependent upon chlorophyll work in plants?

7. In what ways is plant food used to satisfy the needs of the plant itself? 8. Is plant food made and stored in grains, etc. primarily for the good of men who use it? 9. How are plant foods carried about through the plant? 10. What is meant by saying that starch is a storage form of plant food, and sugar a transportation form? 11. What plants produce most of our foods? 12. Do plants as well as animals carry on processes of assimilation of food and processes of respiration?

415. Do plants get hungry? People often speak of the food stored in fruits, grains, stems, leaves, and roots as if those foods were made by plants for the purpose of feeding men. That is men's purpose in selecting and cultivating plants, and therefore they strive to cause plants to manufacture large quantities of the kinds of food which they desire. But plants are living things, and, as such, must have foods by means of which to grow and to replace used or worn-out parts. Green plants have the power of making their own food supply from the simple substances carbon dioxide and water and from the more complex compounds, which include nitrogen, phosphorus, and potassium (Chapter X).

416. The uses of food. If a plant is not interfered with, the food which it manufactures is commonly used by it and for its own purposes. For instance, a part of our food is composed of starch from wheat grains; but if the wheat had not been disturbed, the grains would have fallen to the ground, where, under favorable conditions, they would have started to grow into new wheat plants. These young plants would have used the food stored up in the grain. By harvesting, milling, baking, and eating the wheat we have appropriated for our own purposes that which otherwise might have fed a young wheat plant.

There are several purposes for which food is used in the plant. New material is needed for growth, since both the living protoplasm and the cell walls must be built up from food materials. A less obvious use of food is to furnish energy for the life processes of the plant. A part of the food manufactured by a plant undergoes chemical change by combination with oxygen, which is ordinarily secured through the leaves. This process is called respiration and serves the same purpose in the living plant that respiration does in the living animal. During part of its life the plant stores material in seeds or roots for the nourishment of the next generation of plants.

417. The kinds of foods. There are five classes of foods: carbohydrates, fats, proteins, mineral salts, and water. The first three are of chief importance.

The carbohydrates are already known from our study of the manufacture of plant foods in green plants. The process known as photosynthesis is the source of all the carbohydrates. The most common carbohydrates are starch and several kinds of sugar.

The fats, like the carbohydrates, contain carbon, hydrogen, and oxygen, but in different proportions. Cottonseed oil and olive oil are familiar examples. There is some oil to be found in almost every plant.

Proteins are the materials of which the living substance is composed. They contain the same three simple substances as the carbohydrates (C, H, O), and also nitrogen, with usually

sulphur, phosphorus, and other substances. They are the most complex chemical compounds and are not well understood. Proteins are most familiar to us in the form of the white of egg, cheese, and lean meat.

The mineral salts, such as common table salt, are inorganic chemical compounds. Many of them are of little importance as food materials, and they are never present in large quantities.

418. Where plants use food. Food is necessary in a growing plant as a supply of material from which new leaves, branches, and roots are constructed. It is evident that much of it will be needed in the more rapidly growing parts. Since food is needed by all cells for the process of respiration, food will be needed in all living parts. This means, of course, that there will be need of food to furnish energy everywhere excepting in a few dead tissues like the dry outer bark.

Although food is needed everywhere, it is not made everywhere. Carbohydrates are made principally in the leaves. They may be needed in connection with the growth of roots or the development of the fruit or in other parts of the plant. This immediately raises the question of how food may pass from one part of the plant to the other, for very plainly there must be some method of transfer.

419. Method of transfer. Liquids, and solids dissolved in liquids, are able to pass readily from cell to cell, as we learned when studying the absorption of materials by the roots. It is, of course, perfectly easy to see how sugar may be transferred from one cell to another in this way, for the sugar which is in the plant is dissolved in the sap. By diffusion the sugar may travel from cell to cell in the leaf until it comes to the veins, along which it travels to the stem and so throughout the plant. But what about other food materials? Most kinds of food material in a plant are not soluble. For instance, if we soak a potato or a quantity of rice in water, the valuable materials in them do not dissolve in the water. If they did, we should find it of more advantage to drink the water than to eat the rice or potato. The fact is that in most foods comparatively little of the car-

bohydrates, fats, and proteins dissolve, no matter how long we soak the foods in water. In the examples mentioned the most abundant material is starch, and this is quite insoluble. Since food material is usually found in plants in the form of starch and other insoluble compounds, how is it that it can be transferred to the various parts of the plants where it is needed? Certainly the solid grains, such as the grains of starch, cannot travel far through the plant and remain unchanged.

420. Digestion of starch. The process of digestion of starch and that of other insoluble foods is somewhat similar. In a sprouting seed some of the stored food material is being carried away to be used in forming new parts of the plant. Starch grains from such a sprouting seed should be examined with a microscope. It will be found that the grains of starch are not smoothly rounded, as they would be at any other time, but rough, with many holes on the surface, as if some of the starch had been dissolved from each grain. Of course starch does not ordinarily dissolve in water, but it is rather easily changed into sugar (Chapter X), and the sugar will dissolve. In plants there is a substance called diastase, which has the peculiar property of causing starch slowly to change into sugar if the diastase is brought in contact with the starch. This substance is in the plant sap. It acts upon the starch at the surface of the grains, and the rough, pitted appearance shows where the starch has been so changed and dissolved.

It is not difficult to secure a solution containing diastase by crushing in water some sprouting seeds, such as those of barley. If this solution is mixed with starch in a test tube, it will change starch into sugar as it does in the plant.

The process such as we have just been describing, of changing an insoluble substance into a soluble one, is called digestion. It is possible to transfer insoluble foods from place to place through the plant only after they have been made soluble by digestion.

421. Digestion of other substances. Diastase will digest only the carbohydrates, but there are other substances which have

a similar action on proteins and fats. Substances which, like diastase, cause chemical changes to take place in other substances while remaining unchanged themselves are called enzymes. There are a great many enzymes in plants. Digestion and many other changes are due to them.

422. Transfer in the plant. As pointed out in the preceding paragraph, dissolved food materials may pass from cell to cell throughout the plant. When food reaches the large pores or tubes in the stem, it may pass upward with the general movement of water through the plant. This was mentioned in the discussion of absorption and movement of water (Sect. 412). Passage in a downward direction occurs through tubes in the inner bark. The veins of the leaves are composed of tissues similar to those of living wood and bark, and liquid material moves in these as it does in the wood and bark. The veins are the supporting framework of the leaves, as the woody tissues are the supporting framework of the main body of a plant.

423. Food storage. When the food is in solution and is therefore capable of being transferred from place to place within the plant, it may be disposed of in one of three ways: it may be used immediately for repair and growth, or it may be used to secure energy by means of respiration, or it may be stored.

When food is stored it is usually changed into an insoluble form again. For example, sugar is commonly changed into starch, though there are cases in which sugar itself is stored. Food may be stored in almost any part of a plant, but usually it is stored in large quantities only in much-thickened parts. Examples of thickened storage parts are the potato, carrot, parsnip, radish, onion, beet, sweet potato, various bulbs and tubers, fleshy fruits, and seeds. Very often food is deposited in the roots and other underground parts of the plant. In these cases the food which is made and stored during the summer commonly serves for the plant's growth during the earlier part of the following season.

424. Men and the plant's stored food. The large amount of food which is brought together within a small space makes these

storage organs of plants an important article of food for men and animals. The starch and proteins stored in wheat are two of the valuable things in wheat, and this is the most important single food for the Caucasian race. In the Orient—China, Japan, India—the most important food storehouse is the rice grain, and a very large part of the human race is dependent upon it for their principal food. Rye flour is used for bread in some European countries. Beans and peas contain starch and more protein than almost any other common vegetable food; therefore they are particularly valuable as a substitute for meat in hot countries or in places where meat is scarce.

Corn and oats are used for human food, but not to so great an extent as some of the other grains. They are usually fed to animals, which may then be used as food. A few seeds, such as the castor bean, cotton seed, and corn, store a good deal of oil which is largely used as edible or medicinal oil.

The enormous importance of the industries which are producing these supplies—these great quantities of stored plant food—can scarcely be overestimated. In times of peace as well as in war the quantity and availability of this surplus food is of greatest significance in determining a nation's welfare.

425. Use of food by plants. If the stored food is not used by men or removed in some other way, the plant will finally use it in its processes of growth. When a seed sprouts, for example, it is several days before the young plant pushes through the ground and the chlorophyll is formed which enables the plant to utilize the carbon dioxide of the air. During this time the living material and the cell walls of the stem and roots are made from the stored material in the seed. We know that in the sprouting seed the reserve foods are first made soluble and diffusible (digested) by the action of enzymes, but the wonderful process by which these simple substances become a part of the living material of the cells (protoplasm) is still a mystery. The term "assimilation" is used to cover the constructive process by which new cellular material is made either from reserve material in a seed or from materials manufactured by the plant

in the processes of photosynthesis and protein synthesis. The process of assimilation in plants is undoubtedly similar to the process in our own bodies by which the food which is digested and carried by the blood to the cells of the body becomes a part of the cells.

426. Assimilation and respiration. It will be worth while here to contrast assimilation and respiration. Assimilation is a process by which more protoplasm is constantly made from simple chemical compounds, and it is therefore a constructive process. Respiration is a destructive process by which protoplasm and compounds closely associated with it are destroyed and the energy which they yield is made available.

The whole matter may be represented as like the slope of a hill. We begin at the bottom with carbon dioxide, water, nitrates, etc., and by means of photosynthesis, protein manufacture, and assimilation we ascend to the highest point, protoplasm; the descent on the other side is represented by respiration, which reduces the protoplasm and compounds closely associated with it to carbon dioxide, water, nitrogen compounds, and other decomposition products. Or, another figure may help. Assimilation is constantly building the living structure higher and higher, consuming more and more material and more and more energy in accomplishing this result. Then respiration causes it to break down. The materials and energy used in the building process are released, and the materials may be used again.

CHAPTER XXX

THE UTILIZATION OF FOOD BY ANIMALS

427. Questions for discussion. 1. What would be the result if all the world's cereal crops should completely fail for one season? 2. Why is it that in the wake of armies when they have advanced, one of the first things done is to try to get the devastated soil planted with some kind of agricultural crop? 3. Which is more dependent upon the other, city or country? Why?

4. Is the chief purpose of chewing food that of breaking it up so that it can be swallowed? 5. In human mastication what function is performed by the saliva? 6. If food is swallowed hastily can the saliva do its part of the work of digestion as well after the food is swallowed as before? 7. How does the digested food find its way into the circulatory system?

8. Is it important as a phase of nutrition that food should be palatable? Should we be nourished by good food just as truly if it were not pleasant to the taste as if it were pleasant? 9. Rub the tongue quite dry, then place some sugar on it, and see if you taste the sugar. 10. Close your eyes and allow someone to place coarse sugar or fine salt on your tongue and see whether you can detect at once which you have.

11. Compare the human body with a steam engine in respect to (1) materials to be fed to it; (2) source of materials used; (3) necessity of consumption of materials; (4) how energy secured is used; (5) products; (6) care needed to keep it in working condition; (7) chief sources of wear and tear; (8) what becomes of broken-down organism. 12. What are the effects of putting too much food into the body or swallowing it too hastily?

428. Food a universal necessity. Food, water, air, and, in some climates, shelter, are the great fundamental necessities of all people. Air and water are plentiful enough in most places, and some kind of shelter can usually be contrived, but sufficient food is almost always a problem. In some tropical countries the

natives may be able to secure sufficient food from the rivers and the forests with little labor, but almost all tribes and nations must give a large part of their time and energy to the task of securing food. In civilized countries the largest single business is that of agriculture, engaged in the production of food for men and animals. The value of the product of the farms in the United States is estimated at about fifteen billion dollars. More than half of our people are engaged in this occupation, and when we add to this number those whose business it is to transport, prepare, and sell food products, such as railway workers, millers, canners, bakers, and grocers, it is seen that one of the principal concerns of the people is the provision of food. Even those who are not directly engaged in food trades are spending the larger part of their time in earning money for the purchase of food.

We sometimes forget the fundamental importance of food, particularly in America, where it has been so plentiful; but conditions in Europe and Asia during and after the World War have impressed us all with the importance of food, and how easy it is for misguided governments and peoples to turn the balance from plenty to starvation.

429. The purpose of food. Many people do not consider why they take food into their bodies. Doubtless, if asked to give an immediate answer to the question as to why they eat, many would say that it is to satisfy hunger. In a way such an answer would be correct, but it would be superficial. Indeed, if that were the only reason, it would not be worth while to expend all the time and trouble that we do in eating. One may discipline himself in a few days, as has often been done by men who have fasted, to such an extent that hunger no longer troubles him seriously. If this were continued, death would ensue, though the person, it is said, might not be conscious of hunger for some time prior to his death.

But if not to satisfy hunger, why do we take food? Equally superficial answers that are sometimes given are "in order to live" and "to secure strength." It is true that we could neither retain strength nor life itself without food, but the answers

leave the question of the purpose of food and its work in the body as much a mystery as before.

A clearer notion of the purpose of food will be secured if the body is thought of as a machine and if its way of working is considered.

430. The human body as a machine. It may appear at first sight to be rather fanciful to compare the body to a machine, to an automobile for instance. However, the body is truly a machine in which one may recognize many of the mechanical contrivances mentioned in a former chapter (Chapter XVI), and, like other machines, it can do work when energy is supplied to it.

The automobile is able to move along a level road or up a hill by its own power, just as the body can, but in order to do this the automobile must be supplied with potential chemical energy in the form of gasoline (composed of carbon, hydrogen, and oxygen) and air. The gasoline is burned to supply kinetic energy which drives the pistons and moves the car. Only part of the energy of the gasoline is used in propelling the car, the remainder appearing as waste heat that must be disposed of. The production of energy from the fuel results in some waste material also (carbon dioxide and water) that is passed out through the exhaust pipe.

Like the automobile, the body is capable of moving and of doing work by its own power, but it must be supplied with air and food or it will not long be able to work. It is interesting to notice that three of the important elements in our foods are the same as those composing gasoline, though in different proportions. In the body, as in the automobile, the production of energy for work is accompanied by the production of heat, some of which must be disposed of; and the body too produces wastes, and among the waste materials are carbon dioxide and water. Thus there is much similarity between the two machines, the body and the automobile.

It may be concluded, therefore, that at least one purpose of food is to supply energy for the work that the body does. The

fuel serves but one useful purpose in the automobile, the production of energy. In the body food also supplies materials for repair and growth, as well as energy for work and heat. Each of these uses will be treated more at length in the following sections.

431. Food and work. A large part of the food which is consumed combines with oxygen in the cells of the body and releases energy by which work is done. This is the process of respiration, the same process that was described as taking place in plant cells. People often think of respiration as merely involving the process of taking air into the lungs and then expelling it. That process is breathing, and is merely the preliminary part of respiration. In a later section (Sect. 444) we shall see how oxygen is taken from the lungs to the cells where the process of respiration

takes place. Animal cells are able to obtain energy from carbohydrates, fats, and proteins more or less interchangeably.

The more work a person does, the more food he needs. Work in this sense means something done by the muscles, and may be either work or play in the ordinary sense. Lumbermen and boys of high-school age frequently eat about the same amount of food. If a person spent all his time in bed, he would still be doing a good deal of work just because he was alive. When we



FIG. 207. Effects of poor and good nutrition

The upper photograph is of a rat at the age of five hundred and five days and after prolonged stunting from insufficient food. The rat weighed 53 grams when the upper picture was taken. When the same animal was fed a suitable quantity and quality of food, it gradually increased in weight until at the time the lower picture was taken it had reached 205 grams.

Photographs by Professor Mendel

are resting, the heart contracts about seventy-two times a minute, we breathe about sixteen times a minute, and we make many motions of which we are unconscious. If a lumberman broke his leg and so had to sit quietly, he would need about a third as much food as when working. The weight of the body ordinarily furnishes a good test of whether the right amount of food is used (fig. 207). An adult of normal weight for his height who maintains his weight over a long period of time evidently has about the proper amount of food. A young person should increase steadily in weight, but this should be good muscle and bone and not all fat.

432. Food and body temperatures. It has been seen that when work is done, a part of the energy is converted into heat. When food combines with oxygen to release energy to do work, a large amount of heat is produced. This is the heat which keeps the body warm. Often in summer the heat produced is more than is needed, especially if hard work is being done. The automobile disposes of the excess heat by means of the radiator, and the body gets rid of it by evaporating a large amount of water from the skin (Sect. 156). In winter, on the other hand, we should often be cold if clothing were not used to prevent the loss of heat, or exercise were not more vigorous so that more heat will be liberated.

433. Growth and repair. Another use which the body makes of food is for repair. Changes take place in all the cells of the body. A constant allowance of many kinds of repair material is needed. Body-building during the process of growth requires food. A growing person is constantly forming more bone, more muscle, more blood, more nervous tissue. For these processes the same name is used as in describing similar processes in plant-cell assimilation. Nearly everyone knows that some protein must be assimilated in both repair and growth, but many other things are needed also. Lime and phosphorus are needed for every cell and especially for bone formation. A small amount of iron is also needed for every cell and to make the hæmoglobin, or red coloring material, of the blood.

434. Preparation of food for use. The purposes of food have been outlined. Attention will now be turned to the question as to how the food is taken into the body, where it is finally used, how it is transported, and how the wastes are disposed of, in order that, like a good chauffeur, we may take intelligent care of the machine.

All animals except man take their food just as it is provided by plants or other animals. Man long ago discovered fire and has become accustomed to cooking all the harder and tougher parts of his food, such as corn, wheat, meat, and hard vegetables. Many foods are now subjected to manufacturing processes before they are eaten. Some of these processes modify the flavor or improve the keeping quality, and others make it possible to cook the food in a much shorter time.

Whether food is cooked or not, it must be very thoroughly changed before it can reach the cells of the body and nourish them. Just as the starch which is stored in a seed must be changed to sugar before it can travel in the sap and help to form new cellular material in the growing embryo, so all the complex foods eaten by an animal must be changed to soluble form before they can be used by the body. These changes take place in the alimentary canal, which is composed of several sections, each of which performs one or more special functions related to the use of foods.

435. Mastication. Thorough mastication, like cooking, helps to soften and subdivide the food, but the real work of preparing the food for the use of the body cells is carried out by chemical substances (enzymes) which are emptied into the alimentary canal from various glands. The salivary glands pour into the mouth a fluid containing ptyalin, an enzyme which starts the digestion of starch. This enzyme is similar to the diastase in plants. Thorough mastication is important. The saliva can act only on the surface of the food particles. If the food is divided into small bits, its surface is enormously increased, and the saliva can therefore act more rapidly. This increase in surface also favors equally the action of all other digestive enzymes that

the food will meet in its trip through the alimentary canal. Thus thorough mastication assists digestion in the stomach and intestines. Indigestion may be caused by lack of proper mastication, and some students of the human machine believe that many intestinal troubles are due to this cause.

436. Heavy eating. Poor mastication of food is usually associated with overeating. This may result partly from the fact that poorly masticated food does not readily produce a feeling of satisfaction. Since this is true, a rapid eater continues to eat until he has swallowed an amount of food in excess of what he would have desired if he had masticated thoroughly and satisfied his hunger in a proper way. Not only is this extra quantity of food present in the digestive system, but the starchy foods which should have been digested, in part at least, by the saliva add an extra burden to the later work of digestion. Starch digestion is continued in the intestine by one of the enzymes of the pancreatic fluid. One is in no danger of being too thorough in the mastication of his food.

437. Digestion. The food does not remain long enough in the mouth for much digestion to take place, hence the principal importance of the mouth is with reference to mastication. In the stomach the food meets an enzyme which digests proteins. In the intestine it meets several enzymes which digest the fats and complete the digestion of carbohydrates and proteins. As a final result, by the time the food has passed a short way down the intestine, nearly all the food which can be digested has been converted into soluble substances; these pass with water through the wall of the alimentary canal into the blood and are carried to all the cells of the body. Small residues of food, consisting largely of the fibers of food which cannot be digested and of remaining digestive juices, are carried along into the large intestine and finally expelled as waste.

438. Motions of the alimentary canal. The act of swallowing is voluntary, but when food is once swallowed, it is passed along by a process that is largely automatic. The chief stimuli are the food itself and the secreted juices. Pleasant anticipation of

food has a favorable effect on the whole process ; extreme fatigue or emotion—such as anger, fear, or worry—may entirely stop the digestion of food and its motion along the alimentary canal.

439. Proper care of the alimentary canal. Since the alimentary canal is really a factory in which food is prepared for the use of the cells, it is very necessary that it should have good care. The first responsibility is to take good care of the teeth. We need them all—the flattened front teeth (incisors) for cutting, the pointed canines for tearing, and the bicuspid and molars for grinding. The dentist is a good friend. Furthermore, teeth should be used for their primary purpose. It is important to eat at regular hours and not to eat between meals. The alimentary canal needs to have a rest between meals just as much as the brain needs to have a rest every night.

In order to see that waste materials are not retained in the alimentary canal each one should form the habit of drinking plenty of water every day, eating some food at every meal (such as oatmeal, bread, fruit, and vegetables) which leaves a residue of cellulose, and observing regular toilet habits. If water is taken at mealtime it should not be used to wash down unchewed food.

Since mental states have such an effect on the flow of the digestive juices and on the movement of food along the alimentary canal, everyone should try to see that mealtimes are as pleasant as possible. If one is very tired, it is often better not to eat until after resting.

440. Transportation of food to the cells. In a preceding section it was stated that the digested food passes into the blood and is carried by it to the cells of the body. Much more should be learned about the details of this, but first it is necessary to learn a good deal about the blood circulatory system in order to understand how it transports the food.

The circulatory system consists of the heart, which acts as a pump, and a set of tubes through which the blood flows out from the heart and back to it. These tubes are of three sorts, as illustrated in the diagram (fig. 208). The whole system is

too complex to show in a picture, but the diagram shows the more important facts. The blood leaves the heart in thick-walled tubes called arteries, which divide and redivide into

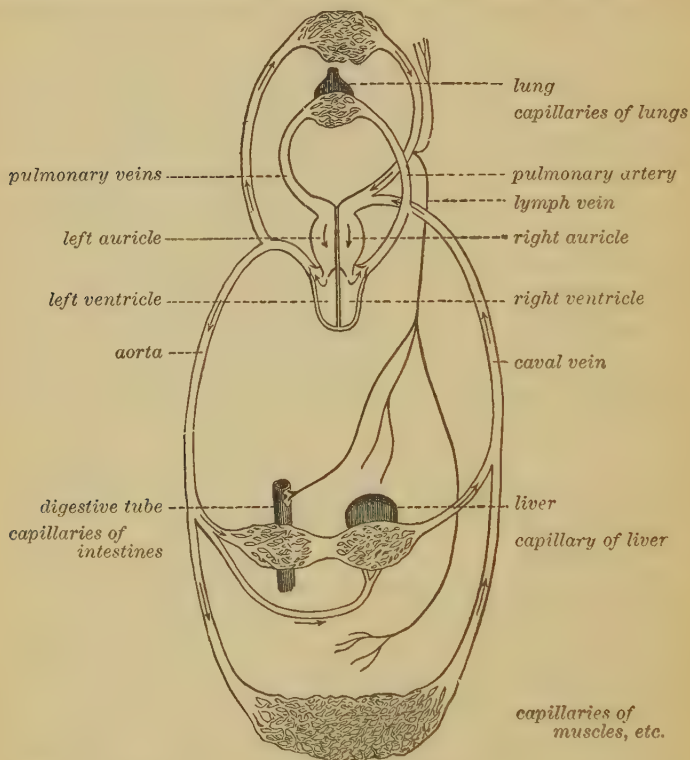


FIG. 208. Diagram of the course of the blood through the body

smaller and smaller branches. These finally connect with a network of very small thin-walled tubes, known as capillaries. The blood passes out of the capillaries into many tubes known as the veins, which are somewhat like the arteries, but not so thick-walled. These small veins unite into larger ones, which finally return the blood to the heart. Find all these parts on the diagram and follow the route of the circulation.

The capillaries are distributed throughout the body. They are so numerous that a needle can scarcely be thrust into the body anywhere without breaking some of them, as shown by the bleeding.

441. The route of the circulation. The course of the blood through the body is shown in a simplified fashion in figure 208. The right side of the heart pumps blood through the lungs. The blood is returned from the lungs to the left side of the heart, which then pumps it through the rest of the body, from which it is brought back again to the right side of the heart. Each side of the heart consists of two chambers separated by a valve. The auricle is a thin-walled chamber which receives the blood on its return to the heart. The ventricle is thick-walled and sends the blood out by a powerful contraction. Trace the course of the arrows in the figure.

442. How food gets into the blood. In the preceding section it was seen that the blood circulates round and round the body in a series of tubes (arteries, capillaries, and veins) that make a complete circuit. With the blood inclosed in these tubes it may fairly be asked how the digested and dissolved food in the alimentary canal gets into the blood, for it would appear that the walls of these blood vessels would effectually separate the blood from anything outside the blood vessels. So far as the veins and arteries are concerned, this is true. Their walls are thick, but the capillaries are different. Their walls are probably something like a ten thousandth of an inch in thickness, and the material of which they are composed is such that water and dissolved substances soak through it readily. It will be seen that this affords opportunity for dissolved materials to pass into or out of the blood while it is in the capillaries.

The walls of the stomach and intestines are crowded with capillaries which lie just beneath the inner surface and therefore close to the digesting food materials. These materials are absorbed into the blood; that is, they soak through the thin layer separating them from the blood in the capillaries and are carried with the blood on its journey.

443. How food gets to the cells. The blood which has absorbed digested food from the stomach and intestines passes from the capillaries into veins and to the heart (fig. 208). It may be seen by examining the diagram that it goes through the lungs, back to the other side of the heart, and then out over the body again. Of course it passes through the capillaries of the muscles, skin, brain, and other organs. These capillaries

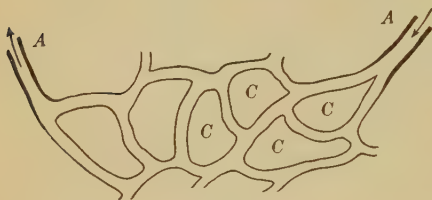


FIG. 209. Diagram of the capillaries

may be represented as in the diagram (fig. 209). In the spaces between the capillaries (fig. 209, C) are the living cells of the body. Between the cells and the blood there is only the thin capillary wall. Dissolved sub-

stances, such as sugar, digested proteins, and oxygen, can easily diffuse out among the cells, and thus the cells are supplied with whatever they need. On the other hand, waste materials from the cells, such as carbon dioxide, can diffuse into the blood and are carried away.

The capillaries are the only place where blood performs its principal functions. The heart and arteries get the blood to the capillaries; the veins take it away. The capillaries in the web of a frog's foot, viewed under a microscope with the blood flowing through them, present a very interesting sight.

444. How oxygen gets into the blood and is used. The lungs contain innumerable minute air sacs into which the air passes when we inspire. On the walls of these air sacs are many capillaries, and the blood in them is separated from the air only by thin walls. Some of the carbon dioxide in the blood escapes into the air and is expelled from the body with the breath. At the same time some oxygen passes into the blood and is carried with it on its rounds (trace the route). When the blood containing oxygen reaches the capillaries of the muscles, brain, and other organs, as described in the preceding section, it passes to

the cells, which use as much as they need. The amount of oxygen used and the amount of carbon dioxide given off by the cells depend upon the amount of work they do.

Taking air into the lungs and expelling it is breathing. Carrying oxygen from the lungs to the cells is circulation. The use of oxygen by the cells and the production of energy is respiration.

445. Removal of wastes. The body, like the automobile, produces waste materials. The principal wastes of the automobile are carbon dioxide and water. The principal body wastes are carbon dioxide, water, urea, and refuse solids. The urine contains the waste nitrogen-containing substances which result from the destruction of the proteins.

Carbon dioxide leaves the blood by way of the lungs; water leaves by way of the lungs, the perspiration glands, and the kidneys; urea leaves by way of the kidneys; the solids leave by the lower intestine. It is very important that these wastes shall not be allowed to accumulate in the body.

446. Digestion, circulation, and exercise. The blood vessels under pressure from the arteries expand or contract and thus regulate the volume of blood flowing through an organ. During the height of digestion the capillaries in the intestinal wall are very much dilated, and the proportion of blood flowing through them is therefore large. This explains why it is so hard to study after a full meal. There is not enough blood flowing through the capillaries of the brain to make it alert and active. Excessive exercise retards the digestive processes. When the muscles are being used, the flow of blood through them is large. At such a time there is not enough blood in the intestinal capillaries to carry on digestion properly.

Wild animals which feed at irregular intervals and eat to fullness when they do feed usually become quiet and often sleep for some time after feeding. In such cases the chief activities of the body are for a time centered about digestion and the circulatory distribution of food. Animals which feed oftener and eat smaller quantities—man, for example—may safely proceed with some sort of mild exercise after eating.

447. Breathing and nutrition. Experiments similar to those suggested in connection with circulation will enable one to determine that the normal breathing rate is about sixteen times per minute and also that violent exercise increases the rate. The tissues demand oxygen, which is secured from the blood. The blood's supply of oxygen is replenished in the lungs, where the waste carbon dioxide is removed. When an increased amount of blood needing replenishment and purification is hastened through the lungs, there is need of more frequent renewal of the air in the lungs. It is the demand for oxygen in the tissues which stimulates an increase in the rate of breathing. Any boy or girl who has run until exhausted knows that at such a time the body needs more air than usual.

Any exercise that tends to increase the air capacity of the lungs increases one's ability to supply his blood with oxygen and to remove waste products from the blood. Deep-breathing exercises are of great importance in increasing the lung capacity. Vigorous exercise is helpful to many persons, since such exercise often compels them to breathe deeply—a thing which they should practice whether compelled to or not.

It needs no argument to show that pure air is better for the body than impure air. The nasal passages are so constructed as to assist in screening out floating particles, such as bacteria and dust. Persons who breathe through the mouth are likely to accumulate dust in the passages leading to the lungs, and in cities with dusty air such persons may accumulate enough dust to prove a menace to the work of the lungs. Collections of dust may become sources of irritation and may be the starting points for the growth of disease germs, such as those of tuberculosis. Air that is breathed inward through the nose in winter is warmed before entering the lungs, but if taken in through the mouth its temperature is changed but little before reaching the lungs and it may chill the lung tissue. "Mouth breathers" should consult a physician to determine whether there is any structural reason for their practice; if not, careful attention will enable them to change the habit to normal breathing.

CHAPTER XXXI

HYGIENIC ASPECTS OF NUTRITION

448. Questions for discussion. 1. Are substitutes for well-known foods (such as cottonseed fat for butter fat) injurious to us? Why do we sometimes object to these substitutes? 2. It is quite possible to develop an appetite in such a way that only a few of the things needed in a balanced ration are desired. Is your appetite so developed?

3. Why is it important to have a balanced ration for men and domestic animals? 4. Is any discrimination shown by insurance companies regarding persons who use alcohol? 5. What do statistics show regarding relative length of life of those who use alcohol and those who do not? 6. Are tea and coffee essential in a well-regulated diet? Why? 7. Secure your state pure-food regulations and report on them in class.

449. The danger signal. Like other machines, the body must have proper attention if it is to work properly, and it is such a complicated mechanism that intelligent care is essential.

Many people who drive an automobile do not understand clearly how all its parts work, but they should know some things about the care of the machine. A good driver sees to it that his machine is at all times supplied with gasoline, oil, water, and a good source of electric current. He does not wait until the machine is in difficulty before supplying these primary needs. If, for instance, the driver neglects to supply oil to the parts that need it, he may be warned of his negligence by its squeaking noise or by other means, but by that time a good deal of damage may have been done. Therefore he does not wait for the warning, but instead gives the car the care it requires before the trouble arises.

In similar manner the body will give notice when it has been neglected or misused, and pain is usually the danger signal. Unfortunately, by the time the danger signal has become in-

tense enough to compel attention, the machine may be seriously damaged. The proper thing to do is to give the body care at all times. Among the most important things to watch are the amount, kind, and quality of food eaten.

450. Amount of food. Since the digestive system is so organized that it can digest carbohydrates, fats, and proteins, and since all these are needed for proper nutrition, it is of much hygienic importance that these foods be used in as nearly proper proportion as can be arranged. If a person eats but one kind of food he is not properly nourished, and the work of digestion is not distributed to the whole digestive system. The appetite may serve as a partial guide to the kind of food needed, but it is not to be trusted fully. This is partly because one is often uncertain concerning the exact kind of food he is hungry for and partly because our habits of eating often cultivate appetites that may not call for exactly what is needed.

Experiments have been performed to determine what amounts of food are necessary for persons who are engaged in active work. It is stated that active workers require from 100 to 125 grams of protein food per day; but it has also been shown that soldiers, teachers, and athletes may work effectively for at least several months upon as little as 40 to 50 grams per day. Similarly, it has been stated that a representative distribution of foods for the composition of an ordinary day's diet may consist of protein, 118 grams; fats, 56 grams; carbohydrates, 500 grams. It must be kept in mind, however, that the above figures are merely suggestive. So much depends upon the materials from which the protein, fats, and carbohydrates are secured and upon such factors as the condition of the body and nature of exercise that statements of definite quantities cannot be considered as an entirely trustworthy guide. It is highly important to make certain that the day's diet includes foods from the various sources—vegetables, fruits, and milk, as well as meat and bread.

It is true, however, that the amounts of food needed may vary greatly according to personal habits, the kind of work in which one is engaged, and the climate. Men engaged in hard physical

work in cold climates demand larger quantities of food than here given and a larger proportion of fats, while people in tropical regions may work better with smaller amounts of fats and more carbohydrates. In the same way the quantity of water needed varies in different climates and with different occupations.

451. Proper balance of foods. Each day we should eat something made from cereals, either breakfast food or bread or rice or macaroni. Both fruit and vegetables should be eaten at least once a day. Most young people like fruit, but many do not like vegetables and should learn to eat them. Fruit and vegetables are important because they help to keep the alimentary canal in good condition; because they contain a number of substances very important for growth, such as lime, phosphorus, and iron; and also because they contain vitamins. Everybody needs some fat. If milk is used, a good deal of fat is secured from that source, and some meats contain much fat; but most people, especially thin people, need to eat some fat in addition to that from these sources. Fat gives more energy than any other food when it is burned in the body; hence soldiers, lumbermen, and other people who need a good deal of fuel generally eat large quantities of it. Each day's diet should include some food rich in protein, such as milk, cheese, meat, fish, eggs, peas, or beans. In addition to its protein, milk contains so many substances important for growth that it should be used every day by growing children. Milk which has been used in cooking has almost the same food value as that which is taken from a glass.

All foods furnish more or less fuel—fat the most, sugar next, and watery fruits and vegetables least of all. An eminent scientist thinks that some day we shall buy our food the way a manufacturer buys coal, according to its fuel value. If we have to economize on food, it is important to know which ones give the most fuel for the money, but we must not omit any important kind.

452. Vitamins. A few years ago it was discovered that sometimes animals that were fed upon a "complete" diet containing

carbohydrate, fat, and protein in proper amounts did not grow and remain in good health. After much investigation it was found that a complete diet must contain a fourth class of substances, in addition to those named above. These substances, whose composition is imperfectly known, are called vitamins.

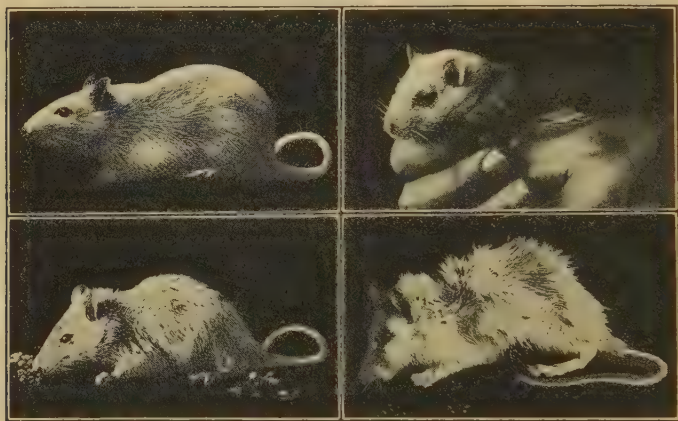


FIG. 210. Vitamins and health

The white rat shown in the upper left is normal and has received a well-balanced diet. Note the smooth fur and plump appearance. The upper right rat did not have the vitamin called vitamin A. In such cases it seems that the eye glands fail to secrete enough of the eye liquids to protect the eye, and it becomes infected by harmful bacteria. If vitamin A is fed, the infection disappears. In the rat with the ruffled and knotted fur and in the rat with the humped back vitamin B has been absent. The absence of vitamin B results in various sickly conditions, such as shown here: partial or complete paralysis, curvature of the spine, and stunted growth. Such animals when fed foods with vitamin B become normal unless bone structures have assumed relatively fixed conditions. Photographs by Dr. Walter H. Eddy

So far as is known the vitamins do not furnish either energy or building-material to the body, and only the most minute quantities are necessary; but if they are absent the body is not able to make proper use of the food furnished to it, and certain serious diseases result (fig. 210). Scurvy, pelagra, beriberi, and other diseases appear to be due to the absence of certain vitamins.

Vitamins are known to be abundant in cream and butter and in most fresh vegetables and fruits. In fact, they are so common that anyone who eats a varied diet, as suggested in previous sections, need have no concern regarding the vitamin part of his diet.

453. Tea and coffee. Tea and coffee have not been mentioned so far in our discussion of food. The reason for this is that they have no food value except that of the added cream and sugar. The feeling of satisfaction which they produce is due partly to the effect of heat on the stomach, but chiefly to the stimulating action of caffeine on the heart and the nervous system. It is a serious mistake for children and young people to drink either tea or coffee. A young and spirited horse not only does not need the lash of a whip but is greatly irritated by it, and so it sometimes happens with human beings and coffee. Even adults should use these beverages with moderation or abstain from their use altogether if their effect is marked. When an emergency arises, such as the necessity of keeping awake all night or of working when one is very tired, a cup of strong tea or coffee may be of temporary assistance. In its lists of instructions for first aid to the injured the Red Cross recommends strong hot coffee as the very best stimulant.

Cocoa differs from tea and coffee in being less stimulating and in containing a little material of real food value.

454. Is alcohol a food? Alcohol is sometimes considered a food because it can be burned or oxidized in the body to liberate energy. It seems hardly safe, however, to describe as a food a substance which has a marked depressing effect on the body, similar to that of such stupefying drugs as ether and chloroform. Alcohol was sometimes used as an anæsthetic before the days of chloroform. In speaking of the properties of foods one noted physiologist has said: "Neither the substance itself nor any of the products of its transformation in the body must be injurious to the structure or activity of any organ. If so, it is a poison and not a food." One of the most harmful effects of alcohol is its injury to the nervous system, but besides this it

is thought to aid in the production of some forms of diabetes and gout. Because of these facts alcohol is classed as a poison rather than a food.

455. Does alcohol make the body warm? We feel warm on a hot day and cold on a cold day, when in reality our bodies are practically at the same temperature; namely, 98.6° F. On a warm day the smallest blood vessels near the surface of the body are dilated and contain much blood, and we feel warm. Conversely, on a cold day these blood vessels are contracted and contain little blood, and we feel cold. Alcohol, when taken into the body, affects the nerves controlling these small blood vessels in the skin in such a way that they are dilated. This results in a rush of blood to the surface of the body, which causes a warm feeling. What is actually happening is that the body is giving off heat with unusual rapidity because so much blood is brought near the surface. Because of this fact a person under the influence of liquor may freeze to death under conditions which a sober person would survive. Abstinence from all alcoholic drinks is a rule among arctic explorers.

456. Alcohol and efficiency. The shocking consequences of taking alcohol in excess are evident to anyone who has seen an intoxicated person. The effect of taking alcohol in so-called "moderation" is less evident but no less certain. It is one of the most insidious dangers of alcohol that it is a habit-forming drug. When the habit has become fixed, the perception of the victim is blunted until he no longer knows or cares whether his use of alcohol is moderate or not and he often loses his attitude of responsibility for his work. This is one reason why so many business organizations, including most railroad companies, will not knowingly employ anyone who drinks even moderately.

Another reason why some business men will not employ a man who drinks is that alcohol, even in small amounts, does not stimulate, but depresses. Even a small amount makes a man less accurate, less rapid in his movements, and less reliable in his judgments. A company working conscientiously to give the maximum wages and to shorten the day of work cannot

afford to employ a staff which is constantly working at less than its best efficiency. A traveling salesman needs all his wits if he is to do his best for the company he represents. A soldier needs a clear brain if his service is to be dependable. In tests which were made in Sweden it was found that a group of soldiers who averaged twenty-three hits out of thirty shots on days when they had no alcohol averaged only three hits out of thirty shots on days when they had moderate amounts of alcohol. It is one of the curious effects of alcohol that a person's judgment in regard to his own accomplishments is not reliable. A person who drinks alcohol seems to himself to be "stimulated," to be thinking more clearly, and to be working faster and more accurately, when the results show that the opposite is the case. A man slightly under the influence of liquor may seem to himself very witty, when to the sober onlooker he seems pitifully silly. Alcohol removes the restraints which are the safeguards of proper conduct.

457. Alcohol and long life. If alcohol be a food, then the continued use of it should in no wise shorten the life of the one who uses it. Life-insurance companies refuse to insure the lives of drunkards, and by keeping careful records have found that even moderate drinking shortens life. An insurance company operates as a business from which the company expects to make a profit. It is therefore not a matter of sentiment but of the result of a study of facts which leads such a business concern to conclude that it cannot risk insurance upon a person who habitually uses alcoholic drinks.

458. Alcohol and the nation. There have been people for many years who have been fully conscious of the damage caused by the use of alcoholic beverages. In the last few years a large amount of clear thinking has been done not only by social workers and physicians, who see the effect of alcohol on the individual and his family, but also by the leaders of industry, who are coming to realize the frightful waste to industries and the state for which alcohol is responsible. An increasing number of people believe that alcohol is such a deadly enemy of

society that its sale should be forbidden exactly as are the sales of other habit-forming drugs, like cocaine and opium. In this country many states passed laws prohibiting the manufacture and sale of alcoholic beverages of all kinds. During the World War the United States adopted an amendment to the Constitution prohibiting the manufacture and sale of alcohol as a beverage.

459. Alcohol and the food supply. When we face the problem of the world's supply of food, alcohol appears in a still different light. In the year 1915 there were consumed in the United States more than 32,000,000 gallons of wines, almost 2,000,000,000 gallons of malt liquors, and more than 100,000,000 gallons of distilled spirits. It is estimated that the grain which could be saved in a year by complete national prohibition would be sufficient to feed 7,000,000 men for a year. Such estimates may or may not be entirely accurate, but that enormous quantities of food are saved by stopping the manufacture of alcohol for drink is clear. Since too little food means bodily and mental inefficiency, since self-respect and the respect of others are assets indispensable to good work, and since sound brains and clear intellects are at a premium, surely alcohol must be recognized as a liability which modern intelligent people will omit from their lives.

CHAPTER XXXII

REPRODUCTION IN PLANTS AND ANIMALS

460. Questions for discussion. 1. If a yeast plant can itself become full grown and produce one new yeast plant in twenty minutes, and this rate continues for twenty-four hours, how many yeast plants will be produced from one plant in that time? 2. Does the rate of reproduction of yeast plants have anything to do with the rate at which fermentation by yeast occurs? 3. How long a time is required for a forest tree to grow to maturity?

4. If possible secure frogs' eggs or toads' eggs and allow them to develop in a dish of shallow water. Trace day by day the stages in development. 5. In what respects is reproduction by eggs similar or dissimilar in birds and flowering plants? 6. What common farm, garden, and house plants are reproduced by vegetative reproduction?

7. From your state agricultural experiment station secure a bulletin on propagation of plants by cuttings and by grafting, and if possible follow the directions given by growing some of the plants at home. 8. Are you more certain of securing the desired kind of cultivated fruits when growing them from cuttings or from seeds? Why?

461. The meaning of reproduction. No matter how well nourished a plant or animal may be, its kind will cease to exist unless there are means by which new and younger individuals can be produced. The process by which younger individuals are produced is known as reproduction, which means "producing again."

In the bodies of plants and animals the cells divide, each cell forming two new cells from one old one. This is reproduction of cells. In most plants and animals increase in number of cells and the enlargement that results is called growth, and not reproduction. Cell division results in reproduction in the case of one-celled animals and plants, as in the bacteria and yeast.

462. Reproduction of the yeast plant. The yeast plant consists of a single spherical or oblong cell (fig. 211). It has a simple wall, within which are the living substances that constitute the protoplasm. Yeasts get their food material from the solutions in which sugar is dissolved, and in doing so partially decompose the sugar; this partial decomposition results in the production of alcohol. When food is abundant the yeast plants enlarge and soon begin the production of new plants. First



FIG. 211. Yeast plants

a, a plant from which a bud has begun to grow; *b* and *c*, plants, each of which has two buds. Greatly enlarged

there may be noted a small, budlike outgrowth on one side of the parent plant. This bud enlarges for a time, then becomes separated. The separated bud is a new yeast plant, and after a brief period of growth it may repeat the budding process by which it came into existence.

Indeed, sometimes a large bud, even before it becomes separated from the parent, begins to form a small bud for the production of the third plant in the series.

Budding represents one of the simplest kinds of reproduction. This is known as vegetative reproduction, because reproduction is accomplished by means of the ordinary nutritive, or growing, part of the plant. Many simple plants and animals are reproduced in a similar way.

463. Reproduction of pond scum. Green "pond scum" floating on the surface of water or submerged is commonly found on ponds and in other standing water. "Pond scum" consists of plants which are very beautiful when seen under the microscope (fig. 212, *A*). Each plant is a silky thread composed of large cells joined end to end. Sometimes, though not often, a thread-like plant is broken into two pieces, when each piece may continue to grow as a new individual. This process is vegetative reproduction, as was seen in the yeast plant.

Certain kinds of pond-scum plants sometimes undergo a different kind of reproduction. When two of these threadlike plants lie close together, the cells of both may send out tubular outgrowths, each of which projects toward the opposite cell (fig. 212, B). These projections continue to grow toward one another and unite their tips in such a way as to form a continuous tubular passage between the cells. When this has been done all the living substance or protoplasm from one cell passes through the tube into the other cell. The two masses of protoplasm unite, and the mass thus formed becomes very compact, and a heavy wall develops closely about it. The old cell walls decay, and the new spherical or oval cell goes to the bottom and passes through a resting period which may last through the winter, or through any other prolonged unfavorable period. At some later time each resting cell grows again, producing a new plant like those that formed it.

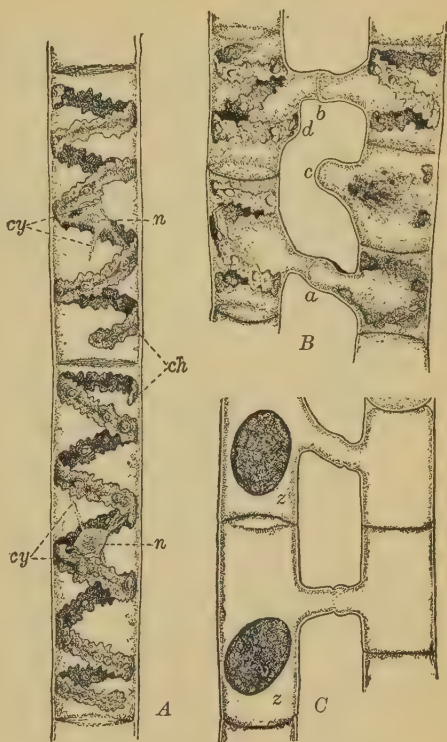


FIG. 212. A pond-scum plant

A, two vegetative cells showing the form of the cell and of the spiral chlorophyll band (*ch*), also the nuclei of the cells (*n*) and the granular part of the protoplasm (*cy*); B, cells showing the beginning of the union of the tubes (*a* and *b*), and tubes which have failed to unite (*c* and *d*); C, completed spores (*z*)

464. Reproduction from sex cells. It is easy to understand how a yeast plant or any other simple plant or animal may have the single-celled body divided so that each division may then become a new individual. It is not so easy to understand the combining of two cells to produce a cell which may then grow into a new individual. In the case of the pond-scum plant described in the preceding section, the protoplasm of a single cell is not capable alone of producing a new plant ; that is, the single cell is not fertile, which means that it alone cannot reproduce. The protoplasm from the cell of an adjacent plant cannot grow alone. It can, however, join with the protoplasm of the first cell and thus make it fertile, or fertilize it. Thus the term "fertilize" refers to the union of two cells to form a single cell which is capable of growing into a new plant or animal.

Reproduction which is brought about by having two cells unite to form the reproductive cell is called sexual reproduction. The cell or spore thus formed may be called the sex spore or sex cell. In pond scum many paired cells of two adjacent plants may produce sex cells, and many new plants may thus be provided for.

465. Each plant or animal from one cell. One sex cell begins the growth of a new pond-scum plant, and by successive divisions of the cells thus formed a many-celled plant may soon be grown. Whether a plant or animal in its adult form consists of one or of many cells, it consists of one cell at first. This is not true usually of plants or animals formed vegetatively, since cuttings, slips, and runners consist of many cells. Sexual reproduction results in the formation of one cell which through growth may become a new plant of many cells. In sexual reproduction each plant or animal grows from one cell which was formed by the union of two cells.

466. The frog's egg. The frog or toad will serve well to illustrate reproduction among animals. Early in the spring, when frogs may first be heard in the ponds, masses of their eggs are easily found. They have the appearance of small black spheres, about a sixteenth of an inch in diameter, embedded in a trans-

parent jelly (fig. 213). They are usually found in large numbers, since a single female may lay several thousand eggs.

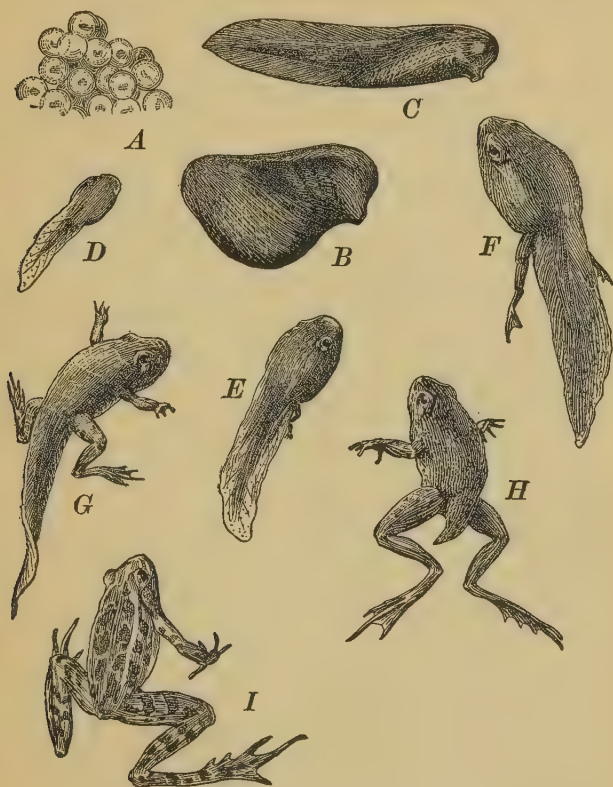


FIG. 213. Development of the frog

A, eggs; *B* and *C*, early stages of the embryo; *D*, tadpole as commonly seen; *E* and *F*, legs appearing; *G* and *H*, front legs appearing and tail disappearing; *I*, mature frog. *B* and *C* are enlarged much more than the other parts of the illustration, the others being approximately natural size

While the eggs appear black as they are seen in the water, it is only the upper surfaces that are dark-colored, the under surfaces being almost white.

Each of these eggs, when laid, consists of a single cell in which is stored a quantity of food material. The egg was formed in the body of the female and expelled into the water when mature. At the same time that the female lays the eggs, the male frog expels from his body into the water a whitish fluid which is shown by the microscope to contain great numbers of very minute cells, known as sperms. The sperms swim about actively in the water and come in contact with the eggs. One of them may enter an egg and unite with it, thus fertilizing it. The fertilized frog's egg resembles the spore of the pond scum in that it is a single cell formed by the union of two cells.

467. Development of the egg. If eggs of the frog or toad are collected carefully and transferred to an aquarium, it is possible to follow the various stages of development at school or at home.

When the egg of the frog has been fertilized it possesses, like the spore of the pond scum, the power of growing into a new organism similar to that which produced it. The first indication of development in the frog's egg is its division into two cells. These again divide, forming four cells, and the process is repeated until the single large cell has become a mass of many small cells. This mass of cells elongates, and the changes from the mass of cells into the different parts of the frog's body are most wonderful. Mouth, eyes, and tail appear, and the young animal wriggles out of the inclosing jelly. Soon it has the complete form of the familiar tadpole.

468. The tadpole. The tadpoles are the young of frogs, toads, or closely related animals. The very numerous, small, jet-black ones are toad tadpoles. All of them resemble fish more closely than they do frogs and toads, so far as appearance and manner of life are concerned. The tadpoles live in the water all the time and breathe by means of gills, as fish do, while the mature animals live upon land much of the time and breathe by means of lungs.

During the hatching period the developing tadpoles have taken no other food than that which was stored in the egg. When they begin to swim about they become voracious feeders, eating minute animals and great quantities of green slime, pond

scums, and other minute plants. They grow rapidly, and legs soon appear from the undersurface of the body. At the same time the tail decreases in size. The gills disappear also, and lungs are formed. Finally, the tadpole, with a form approaching that of the frog but with some remnants of the tail and gills, creeps out upon the land.

469. Reproduction in birds and mammals. In most of the higher animals the fertilized egg proceeds, immediately after fertilization, to the development of the beginning stages, or embryo, of the adult animal. The exception to the last statement is found in the case of those animals which lay an egg that is incased in a more or less heavy coating, like the eggs of birds and turtles, in which the real egg is a cell similar to the one already described. In these cases there is, in addition to the real egg, a large amount of food material, all of which is incased in the covering. In turtles this covering is a thick, tough, leathery wall; in birds it is thin and fragile, though it varies in its strength in different species of birds. The egg of the bird undergoes a period of incubation ranging from fourteen days (or even fewer), in the case of the smaller birds, to four weeks or more, in the case of turkeys, geese, etc. It is possible to discover the stages in the development of the embryo by examining eggs in various stages of incubation. It will be seen that at first the small embryo is reddish in color and that radiating lines of blood vessels extend from it into the food material. The developing embryo soon differentiates bone, muscle, nerve, and other tissues. In a short time the organs that are recognized in the adult bird may be found completely differentiated in the embryo that is still retained within the egg wall. It is apparent, therefore, as already noted, that a development of the embryo within the egg cell has many features in common with the development of the frog.

In the higher animals, known as mammals, and in some others the egg develops into the young animal while still within the body of the mother. In the reproduction of these animals the new individuals are born with their various structures already well formed.

470. Reproduction in seed plants; the flower. Reproduction in seed plants is in some respects quite similar and in others quite dissimilar to that of the animals. The flower (fig. 214) is the reproductive organ in seed plants. It ordinarily consists



FIG. 214. Flower of amaryllis

The sepals and petals are almost identical in shape and color. There are six stamens and one pistil in each flower

of four distinctly different kinds of structures. In a complete flower the lowest floral organs are the sepals (fig. 215), collectively known as the calyx; next above the sepals are the petals, collectively known as the corolla; above the petals are the stamens; and above the stamens are the pistils. In the flowers of some plants the pistils are absent and the flowers are said to be staminate; if the stamens are absent the flowers are pistillate. Sometimes pistillate flowers are borne on some of the branches of a

plant, and staminate flowers on other branches. In other cases the two kinds of flowers are born on wholly separate plants.

471. The pistil. Careful observation of the pistil will ordinarily show that there is a swollen basal portion known as the ovary, above which is a more elongated part, the style, and above that the tip portion, known as the stigma. By opening the ovary we may find within it small bodies, the ovules

(fig. 216), which when mature are the seeds. When we take a very thin section of a young ovule and examine it under the microscope, we see that in its center there is an elongated sac, the embryo sac. At one end of the embryo sac the egg cell is formed. Eggs may therefore be found in the flowering plant just as truly as in animals, but these eggs remain inclosed within the ovary and are not set free as in the frog.

FIG. 215. Diagram of flower, showing the different parts

anther there are many small cells, the pollen grains, which, when the anther breaks open, are scattered in small clouds

472. The stamen. The swollen tip of the stamen is the anther. Within the

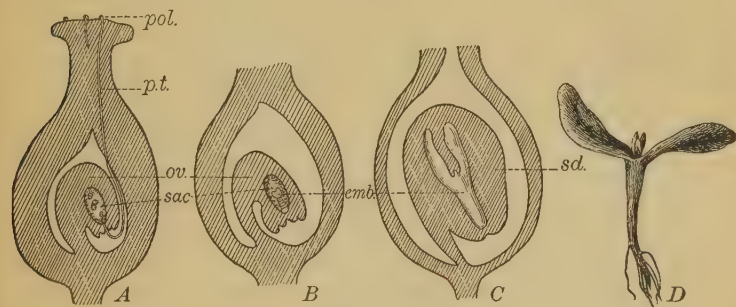


FIG. 216. Diagram to show development of young plant from the egg

A, entire pistil; B and C, development of seed; D, seedling plant; *pol.*, pollen grain; *p.t.*, pollen tube; *ov.*, ovule; *sac*, embryo sac; *emb.*, embryo; *sd.*, mature seed

like yellow dust. When the pollen grains alight on the stigmatic end of the pistil important changes follow. From the

inner wall of the pollen grain there develops a tubular outgrowth which grows down through the stigma and style into the ovule and so reaches the vicinity of the egg. While the pollen tube has been growing down into the ovule two male cells have developed within it. One of these may unite with the egg cell, thus producing the fertilized egg. Each male cell is capable of fertilizing the egg in the ovule.



FIG. 217. A peanut seedling

473. The embryo plant. After fertilization the egg of the plant—like the egg of the frog—proceeds at once to grow. Through cell division and enlargement one region develops into the root tip, another into the stem tip, and others into one or more leaves. In most cases, when the young plant has developed these different regions, the wall of the ovule becomes hardened and the embryo becomes dormant, or rests for a time. This is the mature seed. It may lie dormant for a short or a long period and then grow.

474. The seedling. When seeds of plants are placed in favorable situations, moisture is absorbed by the young plantlet inclosed within the seed coats, and its growth is soon continued. The seed coats are burst; the root tip emerges and grows into the earth and develops additional roots. The way in which the young stem and leaves (fig. 217) emerge from the seed coats is extremely variable. In the seed of the bean there is an elongation of the stem of the young plant. This elongated stem bends in such a way as to pull the leaves out of the seed coats. In other cases, as in the sunflower, the leaves grow upright and push the seed coat into the air, dropping it only after the leaves have become well separated from one another. When the young

plant has become well established in the soil it may continue its growth and eventually produce flowers and seeds which continue the round of reproduction.

475. Vegetative reproduction. In simple plants like yeast it was seen that new plants may be formed by having the growing plant divide; that is, by vegetative reproduction. Many plants and animals are able to have individuals arise directly from the old individual without the production of a fertilized egg. It is possible to cut a twig from a willow or cottonwood tree, place it in the ground, and have it grow into a new tree. One may also take cuttings or slips from geraniums, coleuses, and begonias, and plant them so that they will grow into new plants. Grapevines are started by means of cuttings. The original Concord grapevine has become the parent of millions of grapevines scattered through the civilized world, and this has been brought about entirely by cuttings from the single original grapevine or by cuttings from its descendants.

Different forms of grafting are in a sense types of vegetative reproduction, since they consist in making cuttings from one plant and getting them started to grow upon another plant. It will be found interesting to read agricultural and horticultural books on the subject of grafting to learn of the striking results which may be accomplished by this means.

CHAPTER XXXIII

THE STRUGGLE FOR EXISTENCE

476. Questions for discussion. 1. It is not uncommon for good hens to lay as many or more than two hundred eggs each in a year. If all these eggs should be hatched and all the chickens live, and if half of the chickens should become laying hens the succeeding year, and this process should continue for five years, how many chickens might there be as descendants of the one hen at the end of the five-year period?

2. A good many city people have become enthusiastic about moving to the country and raising poultry because they have calculated how many fowls might possibly be produced from a small number. What are some of the factors often omitted in these calculations? 3. The rate of reproduction inherently possible if unlimited would permit one stand of honeybees to produce enough bees so that in six years Illinois would not furnish standing room for all the hives. Why cannot these enormous figures be realized in fact?

4. How do calculations regarding overproduction help to make it clear that there is a struggle for existence? 5. A mourning dove has been known to devour more than five thousand weed seeds in a single day. Suppose that one pair of mourning doves should devour seeds at this rate for the three summer months, how many would they devour in that time? Do you think they really do devour seeds at this rate all summer? 6. In what way may such birds help the farmer in his own struggle for existence?

477. The fight for life. If we observe a dense forest or a wheat field, we see that there are many kinds of plants that are living under the shade of taller plants. Some of the shaded plants seem to be thriving, and others may show by their condition that they are not doing well. Along a country roadside or in a vacant lot a great number of plants often start to grow in a relatively small space. By observing such a region at successive periods for some weeks it will usually be seen that fewer

and fewer plants persist; and by the time the seeds are ripe the number of plants that have matured is small indeed compared with the number that began growth at the beginning of the season.

Similarly, in a pool of water there may be many hundreds of small fish, tadpoles, and other types of animal life, but only a few mature fish and frogs.

478. Overproduction among plants. We shall get an idea of what causes the crowded conditions upon the earth if we estimate the numbers that might be produced if all the young were to grow to maturity. An ordinary morning-glory plant may bear 3000 seeds in one season; indeed, such a plant often bears considerably more than that number. If each of these seeds should produce a plant that bore 3000 seeds, at the end of the second year there would be 3000×3000 seeds, or 9,000,000 seeds. If the second year's crop of seeds should grow in the same way, at the end of the third year there would be 27,000,000,000 seeds. Similarly, if in the succeeding years all the seeds produced should produce plants like the parent, the one plant with which we began would in five years produce 243,000,000,000,000,000 seeds. If there is an average of 20 feet of vines to each plant, the total length of the vines of the sixth-year crop would reach over 36,000,000,000 times around the earth. Since light travels 186,000 miles per second, how long would it take for it to travel the length of the sixth-year crop of morning-glory plants?

Another illustration may show in a better way the possibilities of plant production. A common kind of garden sweet corn may have 4 good ears on a stalk, 12 rows of grains on each ear, and 20 grains in each row. Therefore one ear may have 240 grains upon it, and one plant may have 960 grains. If each grain produces a new plant the next year, and this process continues for five years, the fifth-year crop will consist of 3,397,346,240,000 ears. That would be over 30,000 ears for each person in the United States, or 2 ears per day for each man, woman, and child for over fifty years.

Calculations which can be made in your class work will show equally well what enormous numbers of individuals would soon be produced if possibilities were allowed to become realities. Jordan says, "An annual plant producing two seeds only would have 1,048,576 descendants in twenty-one years if each seed sprouted and matured." It is a matter of common knowledge, however, that the enormous reproduction suggested by these figures does not really occur.

479. Overproduction among animals. Animal reproduction in enormous numbers is also possible. A single female codfish has been known to produce as many as 9,100,000 eggs in one year. A female salmon four years old may lay 4000 eggs. If half of these 4000 eggs grew into female salmon and produced 4000 eggs each, as did their mother, there would be 8,000,000 eggs. If we suppose that each of these 8,000,000 eggs grows into an adult salmon four years old and weighing 20 pounds (although four-year-old salmon often weigh more than 20 pounds), there would be 160,000,000 pounds of salmon in this third-generation crop. If these salmon were packed in tins and should net three fourths of their original weight, or 120,000,000 pounds, and should be sold at ten cents per pound, they would be worth \$12,000,000; or if the inhabitants of a city of 10,000 people were to use an average of one fourth of a pound per day for each person, the third generation of salmon would supply this city for forty-eight thousand days, or for more than one hundred and twenty-one years.

Any given species of animal has a rate of reproduction which makes enormous numbers of that species possible if we assume that this rate is to have no limitations. Many an enthusiastic resident of a city has made calculations regarding the number of chickens that may be produced within a few years from a small initial number of chickens. Some city residents have even moved into the country expecting to produce chickens at rates comparable to these inherently possible numbers. They have found that important limiting factors prevent the realization of their expectations.

In the first place, it is clear that there is not enough space for more than a small part of the new individuals to develop. Every open space that offers anything like reasonable living conditions for plants and animals is soon occupied by them. If the fifth-year crop of sweet corn, as calculated above, were planted as corn is ordinarily planted, it would require about two thousand times the land area of the state of Illinois in which to plant it.



FIG. 218. Struggle for existence among birds during the nesting period

In the area shown in the photograph there were twenty-four nests containing young birds or eggs. The parent birds range over a much larger area in securing food for the young birds, but it is evident that if all are adequately fed, these young and old birds are important factors in the struggle for existence in this locality. Also, since much of the food of these birds consists of insects harmful to vegetation, the birds are important economic factors. The kind of nest in each location follows: 1, brown thrasher; 2, orchard oriole; 3, robin; 4, robin; 5, robin; 6, brown thrasher; 7, catbird; 8, catbird; 9, brown thrasher; 10, robin; 11, orchard oriole; 12, cedar waxwing; 13, robin; 14, robin; 15, kingbird; 16, brown thrasher; 17, catbird; 18, robin; 19, robin; 20, robin; 21, catbird; 22, bronzed grackle; 23, robin; 24, robin. Photograph by C. W. Finley

Space is too limited for any given kind of plants or animals to increase very rapidly. In a rich river bottom, in a vacant lot, in almost any place where plants and animals may get started to grow, the struggle for space is evident. In the tree tops the birds contend for nesting places (fig. 218). The English sparrow has driven many native birds away from their former nesting-places. Agriculture has taken over the territory

formerly occupied by many kinds of native plants and animals and has introduced other kinds of plants and animals into the old haunts of native living things.

480. Not food enough for all. The city man who would make a fortune growing chickens finds that his expense for feed is large, often so large that he cannot afford to raise chickens; and if the possible rates of increase are made real for even a short period, it is soon evident that neither space nor food is sufficient. The tragedy of the shortage of the food would be seen constantly if it were not for the fact that one kind of living thing may serve as food for one or many other kinds. When salmon become quite abundant, other kinds of fish, or other animals, may devour them in large numbers. In other fresh-water streams and lakes the black bass may produce hundreds of eggs and guard them until the young are hatched and are a few days old. After the mother fish has left her young, she as well as other fish may catch and devour any of them that are not so fortunate as to escape when pursued. In this way not so much food is needed for young salmon and young bass, because some of these fish have become food for others. In any kind of living things the few that reach maturity are to be looked upon as the ones that have been able to secure enough food to nourish them and enable them to grow while at the same time avoiding the catastrophe of serving as food for some other hungry animal.

481. Climatic dangers. An unexpected and severe storm in early summer leaves in its path a mass of wreckage, such as broken trees, flattened grain, overturned nests of birds, drowned nestlings, and insects killed by wind or water. The small and inconspicuous forms of life that are killed are more numerous than the larger ones. At other times sudden changes in temperature prove extremely destructive. When migratory birds are caught in snowstorms many die. The American golden plover flies southward in the autumn migration over the Atlantic Ocean from Nova Scotia to the Lesser Antilles or even to South America. Often these birds are caught in heavy storms,

many doubtless perishing at sea and many being driven ashore in an injured condition. Rainstorms accompanied by hail cause the death of young birds, insects, and some larger animals, and of large numbers of plants. Excessive heat, drought, and other climatic causes are important factors in the elimination of living things.

482. Destruction by disease. A visit to a field of corn or wheat will usually enable one to discover a parasitic plant known as smut growing upon the corn or wheat. This smut secures its nourishment from the host plant. After a time it produces its reproductive spores, by means of which new smut parasites may get started on new host plants. But the host plant suffers and may be killed by the smut. Its supply of nourishment may be taken by the smut, or the smut may produce poisonous substances that severely affect the host. The smut is merely growing in its own way, but in so doing it may cause the death of other plants.

Bacteria, fungi, and some animals cause the disease and death of other living things. So universal is disease that we scarcely know what is meant by "natural death." In nature, when animals begin to get old and their bodies operate less effectively than when they were younger, they are more readily captured by food-seeking animals or are more susceptible to disease. In nature so-called natural death of animals rarely if ever occurs, since they are usually killed by their enemies or by disease.

483. The balance of life. The grass of the field is eaten by herbivorous animals, and herbivorous animals are eaten by carnivorous animals. It might seem, therefore, that the number of carnivorous animals is limited by the available grass for grass-eating animals. But the balance of life is maintained by complex relations between many kinds of living things. When a grasshopper lays its eggs, the animals that can use the eggs as food begin to destroy them if they find them. If the eggs hatch, the young grasshoppers begin at once to eat the tender leaves of grass and other vegetation. When there is a large number

of grasshoppers, there is danger of destruction of the kinds of vegetation that are used as food, and in any case the vegetation may be held in check. But birds feed upon grasshoppers, a single bird often eating in one day as many as the entire brood of one mother insect. A California meadow lark was known to eat 314 grasshoppers in one feeding, and flickers have been known to devour over 5000 ants in one day. Obviously the insects that survive are the ones which, while getting their own food, escaped the birds and also the diseases and climatic dangers that surrounded them.

The birds that devour the insects are themselves the food for other animals; they too are in danger of disease, cold, heat, and drought, and but relatively few of them survive. Every natural region is to be looked upon as a society of living things, each one of which bears certain definite relations to some or many of the others. The squirrels in the woods thrive fairly well, and in undisturbed nature their number remains fairly constant. If they increase too rapidly, their food supply becomes too small or their enemies thus find a larger supply of food and likewise thrive, and in so doing reduce the number of squirrels. If the squirrels are removed from their normal regions, where they play a part in the balance of life, they may fail completely or may find new and unusual conditions well suited to them. How closely living things are related to their surroundings may be shown by supposing a change in living-places between a wolf of the Western plains, a squirrel of the central-states forest, and a fish of the Gulf of Mexico. None of these would survive if placed in the region in which either of the others lives.

484. Disturbing the balance of life: the Japanese beetle. Man has disturbed the natural balance of life wherever he has gone. When he cuts a forest, plows a field, drains a swamp, or builds a city, many kinds of life are destroyed either directly or because the necessary conditions of life are removed. Agriculture and horticulture, in fact, are attempts of man to introduce new kinds of life where they did not exist. The destruction of the wheat crop by insects, of cotton by the boll weevil, and

of apples by the codling moth are evidence that as yet man has not succeeded in maintaining his artificial balance of life without great loss.

A specific illustration of what occurs when men unwittingly introduce new insects into this country is shown by the facts regarding the Japanese beetle in New Jersey and Pennsylvania. In Japan, the home of this insect, the beetle is harmful but not



FIG. 219. Diagram showing yearly extension of the Japanese beetle in New Jersey and Pennsylvania since 1916

devastating, because it seems to be held in check by its natural enemies. No one yet knows what these enemies are, though students are trying to find out.

In 1915 this beetle was first discovered in the United States, at a single location in New Jersey.

This insect devours almost all kinds of plants—leaves of garden plants, of field plants, even of weeds. It eats the roots from grass to such an extent that the sod may slide in hilly places. If unchecked the insect will devastate large regions and cause

loss of crops and consequent loss in animal life. The area covered by its advance is shown in the map on page 425 (fig. 219). The rate of advance is shown as follows:

YEAR	AREA INFESTED	STATE
1916	1 square mile	New Jersey
1917	2 square miles	New Jersey
1918	6 square miles	New Jersey
1919	48 square miles	New Jersey
1920	103 square miles	New Jersey and Pennsylvania
1921	269 square miles	New Jersey and Pennsylvania
1922	800 square miles	New Jersey and Pennsylvania
1923	2500 square miles	New Jersey and Pennsylvania

485. Disturbing nature's balance of life: the rabbit. The common rabbit was introduced into Australia and, finding favorable conditions, multiplied astonishingly. Under favorable circumstances a pair of rabbits will produce each year six litters, averaging five young in each. Since rabbits feed upon vegetation, when present in large numbers they competed with cattle and sheep to such an extent that the grazing industry was almost destroyed in some sections of Australia.

Professor Sidney Dickinson in a discussion about ten years ago said:

The original pair might be responsible in five years for a progeny of over twenty millions. That the original score that were brought to the country have propagated after some such ratio, no one can doubt who has seen the enormous hordes that now devastate the land in certain districts. In all but the remoter sections the rabbits are now fairly under control; one rabbit with a pack of dogs supervises stations where one hundred were employed ten years ago. Millions have been killed by fencing in the water holes and dams during a dry season, whereby they died of thirst and lay in enormous piles against obstructions they had frantically and vainly striven to climb, and poisoned grain and fruit have killed myriads more.

Another great pest to the settlers is developing in the foxes, two

of which were imported from Cumberland some years ago by a wealthy station owner, who thought that they might breed and give himself and friends an occasional day with the hounds. His modest desires were soon met in the development of a race of foxes far surpassing the English variety in strength and aggressiveness, which not only devour many sheep, but out of pure depravity worry and kill ten times as many as they can eat. When to these plagues is added the ruin of thousands of acres from the spread of the thistle, which a canny Scot brought from the Highlands to keep alive in his breast the memory of Wallace and Bruce, and in New Zealand the blocking up of rivers by the English water cress, which in its new home grows a dozen feet in length and has to be dredged out to keep navigation open, it may be understood the colonials look with jaundiced eye upon suggestions of any further interference with Australian nature.

Not to be outdone by foreign importations, the country itself has shown in the humble locust a nuisance quite as potent as rabbit, fox, or thistle. This bane of all men who pasture sheep on grass has not been much in evidence until within the last few years, when the great destruction of indigenous birds by the gun and by poisoned grain strewn for rabbits has facilitated its increase. The devastation caused by these insects last year was enormous, and befell a district a thousand miles long and two thousand miles wide. For days they passed in clouds that darkened the sky with the gloomy hue of an eclipse, while the ground was covered with crawling millions, devouring every green thing, and giving to the country the appearance of being carpeted with scales. It has been discovered, however, that before they attain their winged state they can easily be destroyed, and energetic measures will be taken against them throughout all the inhabited districts of Australia whenever they make another appearance.

CHAPTER XXXIV

PARENT AND OFFSPRING

486. Questions for discussion. 1. Examine a dozen or more ears of corn and note the ways in which they vary. Can you find two ears of corn exactly alike? 2. Of all the human beings you have ever met, are any two exactly alike? 3. In a herd of one hundred or one thousand pigs, horses, or cattle are any two exactly alike? 4. Are any two children of the same parents exactly alike? 5. Are the children of the same parents more alike than they are like the children of other parents? 6. Do half-brothers and half-sisters resemble one another as closely as do full brothers and full sisters?

7. What is meant by the law of variation? the law of resemblance? 8. How does artificial selection differ from natural selection? 9. To what extent have domesticated cattle and horses helped to determine by artificial selection what kinds of native plants may remain in our pasture lands?

10. Do the growth habits of the plants which remain in pasture lands help to explain how they have succeeded in the struggle for existence? 11. How has artificial selection in horticulture and floriculture affected such plants as apples, oranges, and chrysanthemums? 12. Potatoes occasionally, though very rarely, develop seeds from flowers. Potatoes are not commonly reproduced from seeds, but from the underground tubers. How can you account for this fact?

487. Individual differences. When one of the authors of this book was a boy he was told by his father to go to the river bank and find two pebbles exactly alike in all respects. The boy cheerfully undertook the task, but has never been able fully to meet its requirements. A casual observer, when looking at a forest, would say that many of the trees cannot be distinguished one from another. When he looks closely and attempts to verify his conclusion, he finds himself in difficulty. It is highly improbable that any forest, however large, contains two trees

exactly alike. It will be instructive to try to find two exactly like objects of the same kind ; for example, leaves of an oak or maple tree, pebbles on the shore of a lake or bank of a stream, or chickens or pigs in a barnyard.

While we should have difficulty in finding like objects of the same kind, we should rarely fail to recognize resemblances in the same kind of objects. Most people readily recognize oak trees, and some people can distinguish between red oaks, white oaks, black oaks, etc. Even the descendants of the same set of human parents have such resemblances that we usually recognize their relationship. One family may have common characteristics that separate them from other families of children, but the different members of the family have distinctive individual characteristics.

488. The nature of variation. Individuals of the same kind may differ from one another very widely (fig. 220). If one selects the most widely different grains of corn that he can find on a single ear, he will usually be surprised at the variation. This is still better shown by selecting grains from different ears grown in different places.



FIG. 220. Variation in wheat

These heads are taken from wheat that was grown by the Pima Indians. Note the wide differences in characters of the heads. The number of inferior heads is so great that the yield would be small.

Photograph by R. M. Mead

Equally great variations are found in other seeds. For instance, the seeds of the common ragweed usually have distinct spines upon the surface, but the number of spines varies. The form and surface of one hundred and twenty seeds were studied. The table below shows the variation found in the number of spines in these seeds:

Number of spines	1, 2, 3, 4, 5, 6, 7, 8, 9
Number of times occurring in 120 ragweed seeds	1, 3, 7, 9, 25, 37, 25, 12, 1

The plant known as "Spanish needles" has conspicuous yellow ray flowers. The number of the ray flowers varies, though this variation is often unnoticed. A count of three hundred and twelve heads of this plant was made, and the following table resulted:

Number of ray flowers	3, 4, 5, 6, 7, 8, 9, 10, 11
Number of times occurring in 312 flowering heads	2, 3, 8, 16, 52, 221, 9, 0, 1.

Not only the form or the number of parts varies, but also the chemical composition. In connection with attempts to grow the best types of corn for the different needs of agriculture and other industries, careful studies were made to determine the percentage of oil and of protein substances in corn. It was found that in some of the ears the percentage of protein was as high as 12.54 per cent, while in others it was as low as 8.96 per cent. The oil content also ranged from 5.39 per cent to 4.03 per cent.

489. Hybrids. Hereford cattle are commonly regarded as amongst the best of the beef-producing breeds (fig. 221). In some parts of the United States these and other breeds of cattle have been seriously affected by a disease known as "Texas cattle fever," which is carried by the cattle tick. The cattle industry has suffered greatly from this cause. The zebu, or Brahman cattle, of India (fig. 221) are immune to the tick and are thus free from the disease which the tick carries. The zebu is not so good for beef production as the Hereford cattle. Certain cattle-

growers decided to try the experiment of interbreeding Herefords and zebu, in the hope that the offspring might possess the desirable beef qualities of the Hereford with the tick immunity of the zebu. As a result of this experiment offspring were



FIG. 221. Breeding of hybrids

Above, Hereford cow at left and Zebu bull at right; below, first-generation offspring of these types of parents

produced (fig. 221) showing various characteristics of the two kinds of parents. Offspring produced by crossbreeding are known as hybrids.

Some of the cattle produced as a result of the experiment just cited resemble the Hereford, some resemble the zebu, and some bear partial resemblance to both parents. Some of the off-

spring retain the form and beef qualities of the Hereford and also retain the zebu's immunity to the cattle tick. Some of the individuals which retain these qualities are used as parents for the production of other cattle, with the hope that the descendants of these hybrids will continue to retain the desired qualities. Moreover, it has been found that so large a percentage of the first generation offspring from zebu bulls and Hereford cows are immune to cattle tick and also possess good beef qualities that there has been a large demand for a supply of zebu bulls. But the need for such a new breed of cattle is not now so great as when this experiment began, since methods of ridding cattle of the ticks have been found and are being applied.

Among plants and animals many hybrids are constantly being produced. Hybridization presents an important method of production of variations.

490. Natural and controlled selection. Whenever variations occur we may to some extent determine which variants shall have a chance to reproduce their kind. In the next generation variations will again appear, and selection will again be necessary if it is desired to perpetuate and to improve the type with which the work began. A race of plants or animals may be made less variable by selecting constantly for certain qualities and by eliminating the variations which are not of the kinds desired.

Men who are interested in plant and animal improvement decide which ones of all the variations are desired, and then try to maintain these types by careful control of them. This constitutes controlled or so-called artificial selection. In open nature, through natural selection, those things that can live are the ones that do live. For example, the animals of the extremely cold countries vary in the thickness and heat-retaining qualities of their coats of fur. They vary also in their fleetness in pursuit of food, in their ability to escape enemies, and in their physical endurance of the severe conditions of their environment. Those whose variations best fit them for their environment are usually the ones that persist. The others die of hunger

or of physical hardships or by being caught and killed by their enemies. In succeeding generations, year after year, variations occur, and the animals that can endure the conditions of their environment are the ones that mature and establish the succeeding generations of their kind.

491. Changes in environment. Any change in the environment affects the living things within it. The changes in plant and animal life are in themselves fundamental changes in the environment, for plants and animals are a most important part of the environment. For example, when wolves, foxes, and rabbits occur in undisturbed nature in their usual numbers, only those rabbits can live which can escape from the wolves and foxes and other enemies. If we suppose that there is an epidemic of disease which kills off all the wolves and foxes over a territory of one hundred square miles, the environment for rabbits is greatly changed. Under such conditions many rabbits can live which could not live if the wolves and foxes were present in their usual numbers. Thus the changed environment, so far as these factors are concerned, is favorable to the life of a larger number of rabbits.

What do rabbits live upon? In one region in which they live in winter they eat large quantities of buds from low shrubs (as young trees of sassafras, hawthorn, etc.). An unusual increase of rabbits thus greatly affects the environment for plants upon which rabbits feed. In this way the supply of food may become exhausted, and starvation of many rabbits may result, largely because so many of them have succeeded in escaping animals that ordinarily prey upon them.

The environment changes, therefore, for wolves and foxes, for rabbits, and for the plants upon which rabbits feed, but these are only a small part of the factors that make up the natural environment in any region. This constant change in the environment means equally constant change in the kinds of things that are able to live. Variants that can live in one environment may sometimes be unable to live in the same region when it has undergone extensive changes.

492. Results of natural selection. We have seen from our studies of overproduction and variation that many variable forms are introduced upon the earth, most of them failing to live to adult size and perpetuate their kind. The living plants and animals now found are to be looked upon as the few that have persisted. Not only this, but natural selection is still



FIG. 222. Diversity of form produced by selection and breeding
Five varieties of chrysanthemum. All chrysanthemums have descended from
a common ancestor similar to the small upper left-hand specimen

going on, and we must not look upon the things now living as the final types of inhabitants of the earth. They are merely the present results of nature's processes, and nature is still working.

493. Controlled selection. Man selects those variations that give promise of being advantageous to him in some way. He tries to adjust the environment about these plants and animals so as to produce the best results. If he wishes to produce an animal that will furnish beef in large quantities, he selects and

grows the variety which most nearly resembles his ideal. He then tries to create the most favorable environment by careful feeding, pasturing, and housing, and by warding off disease. In the same way sheep, swine, driving-horses, corn, wheat, coffee, carnations, and roses are selected and grown under artificial conditions, and results are produced which are often very unlike those found in undisturbed nature (fig. 222).

494. Progressive results of controlled selection. The Illinois Agricultural Experiment Station has performed some important experiments to determine the possibilities of changing the food values in different kinds of corn. The accompanying tables, based upon ten years of experiment with corn-breeding, show that by constantly eliminating the undesired variations and maintaining the desired ones it is possible to improve certain characters. In studying the first of these tables note the gradual increase of the percentage of protein materials in one lot and the corresponding decrease in the other lot. For feeding purposes the corn with the largest amount of protein would be more valuable.

TEN GENERATIONS OF CORN WHICH WAS BRED FOR
INCREASE AND DECREASE OF PROTEIN

YEAR	HIGH-PROTEIN PLOT; AVERAGE PER CENT PROTEIN		LOW-PROTEIN PLOT; AVERAGE PER CENT PROTEIN		PER CENT OF DIFFERENCE BETWEEN CROPS
	In seed planted	In crop harvested	In seed planted	In crop harvested	
1896	—	10.92	—	10.92	.00
1897	12.54	11.10	8.96	10.55	.55
1898	12.49	11.05	9.06	10.55	.50
1899	13.06	11.46	8.45	9.86	1.60
1900	13.74	12.32	8.08	9.34	2.98
1901	14.78	14.12	7.58	10.04	4.08
1902	15.39	12.34	8.15	8.22	4.12
1903	14.30	13.04	6.93	8.62	4.42
1904	15.39	15.03	7.00	9.27	5.76
1905	16.77	14.72	7.09	8.57	6.15
1906	16.30	14.26	7.21	8.64	5.62

For the manufacture of corn oil it is desirable to secure varieties of corn having a large proportion of oil. In the table on page 437 it will be possible to note the gradual separation of two races of corn which differ greatly in the proportion of oil present, though all have descended from the same original lot of corn. The figures at the top and in the margins represent percentages of oil; those in the body of the table show the number of ears of the indicated composition.

It is likely that if all these samples of ears of corn had been left to grow side by side, no such differentiation of the two races would have developed. They have been separated from one another only by selection and perpetuation of the desired types and by elimination of the others.

495. Controlled selection in milk production. To most persons the difference in milk cows appears in variations in general form, color pattern, or in quietness of disposition. Such qualities are important, but the chief question is, Does the cow produce the desired quality and amount of milk? A first-class cow should provide milk for an ordinary family and an additional amount which can be sold. Her production when estimated in terms of her own cost and maintenance should leave a credit balance instead of a deficit. Many cows which are kept on American farms do not pay their way; they are boarders which do not pay all their bills.

During the past twenty-five years science has been called upon to help solve the problems of milk production. First, the "star boarders" were dismissed. It soon became clear, however, that it was not sufficient merely to dispose of the poorest stock. A study of milk cattle showed that some of those with high production have their good qualities appear fairly regularly in their offspring. Others, even though good as individuals, do not transmit their good qualities so regularly. When selection is made from the better types, fewer "boarders" appear in the offspring.

The value of a milk cow is determined both by the number of pounds of milk produced in a year and by the number of

PROGRESSION IN HIGH AND LOW OIL CONTENT OF "ILLINOIS" CORN

YEAR	AVERAGE % OIL IN SEED	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25	8.50	AVERAGE % OIL IN CROP			
1896											1	15	20	41	36	25	15	5	4	1												4.70		
1897	High 5.39 Low 4.03									1	5	7	9	10	15	19	24	3	7	1													4.73 4.06	
1898	High 5.20 Low 3.65								8	9	31	31	19	9	1	37	50	35	24	22	6	2	2	1									5.15 3.99	
1899	High 6.15 Low 3.47						1	2	5	32	36	36	23	8	1	2	10	16	22	24	18	12	3										5.64 3.82	
1900	High 6.30 Low 3.33					1	3	8	32	39	32	20	6	3	1	1	3	9	18	16	30	18	9	2	1								6.12 3.57	
1901	High 6.77 Low 2.93						2	12	34	43	29	5	1			2	3	10	13	26	21	28	15	7	1								6.09 3.43	
1902	High 6.95 Low 3.00				1	6	34	19	16	9	5					2	5	3	10	13	18	16	13	9	1								6.41 3.02	
1903	High 6.73 Low 2.62						1	3	26	33	22	5				1	10	10	10	19	18	21	13	5	2	1								6.50 2.97
1904	High 7.16 Low 2.80						3	7	42	31	15	4			1					3	9	8	12	15	18	18	8	6	2	1			6.97 2.89	
1905	High 7.89 Low 2.67																				4	9	19	15	21	17	19	7	5	4			7.29 2.58	
1906	High 7.86 Low 2.20																			1		5	9	24	16	32	20	8	2	3			7.37 2.66	

pounds of butter fat which it contains. The butter fat is the more important of the two factors. A cow which produces 250 pounds of butter fat in a year is much better than the average American cow, but there are some exceptional cows which produce more than 1000 pounds of butter fat in a year.



FIG. 223. Countess Prue

This famous cow is the result of many years of patient study of the principles which produce the best type of individual cow. Of her thirty ancestors in the four preceding generations, all but one were registered. Several of these ancestors were famous individuals. Countess Prue in one year produced 18626.90 pounds of milk which contained 1103.28 pounds of butter fat

There are several important types of dairy cows in all of which the process of controlled selection is going on. The Guernsey type (fig. 223) will be used as illustration here, since it not only presents the essential facts, but its numbers have been relatively small and the records less complicated. To be recorded in the Advanced Register a cow must produce 250.5 pounds of butter fat in one year, beginning at two years of age, and the amount required increases at a stated rate for older cows. At the beginning of 1923 there were 9480 cows recorded

in the Advanced Register of Guernseys. Of this number 2333 are outstanding individuals, as shown by the following grouping:

Each of 2333 cows produced 600 or more pounds of butter fat in a year. Of the 2333 cows 194 cows produced 800 or more pounds of butter fat in a year. Of the 194 cows 16 cows produced 1000 or more pounds of butter fat in a year.

A study of the ancestry of these high-grade cows, leading back to the earliest official records in this country and in the Isle of Guernsey, shows a long line of high productivity. This line leads more or less directly to a famous Guernsey Island sire known as Pretor 14. By no means all of the 2333 high-record cows are descended from Pretor 14. The best ones, however, and by far the largest number, are of this descent.

In recent years three lines of American Guernsey breeding have produced nearly all the high-record Guernsey cows. All three of these lines are descended from Pretor 14. In each of these three lines there is an outstanding sire. The most famous of these sires (Ne Plus Ultra 15265) has eleven Advanced Register ancestors within the past four generations. Of these eleven ancestors, seven are descended from Pretor 14. It is clear why those who are endeavoring to improve their Guernsey herds are usually desirous of securing individual cows or sires from one or the other of the three main lines of Guernseys.

Obviously in controlled selection there must be something worth while to select. Then most careful and prolonged attention is necessary in producing and maintaining the highest quality of result.

496. Selected types not easily maintained. The plants and animals developed artificially by man could not persist long in their present form if they were removed from his care. A corn-field if left uncultivated from year to year would probably, even in its second year, be more conspicuous for its weeds than for its corn. Farm animals if left to care for themselves would doubtless, in most cases, soon cease to exist or would rapidly change their habits and appearance. A poultry yard if deserted by man would soon be cleared of chickens by marauding

animals, by disease, or by starvation. A rose garden requires constant care to prevent its losing the high type of flower production desired by man. An apple orchard under relaxation of care very soon becomes infested by disease and reverts to relative nonproductivity. Man's artificially selected types are in a condition of high tension, which is soon relaxed, partly or wholly, when he ceases to select and to care for them. These conditions are well shown in neglected orchards and on abandoned farms, where cultivated plants are gradually giving way to native wild plants.

497. Inheritance. Much that has been said bears more or less directly upon the topic of inheritance. "Heredity is the rule of persistence among organisms." It is an old saying that "like begets like" and "blood will tell." While we know that organisms vary from one generation to another, we also know that they resemble one another with varying degrees of resemblance. We expect individual characteristics of parents to be more or less represented in the individual characteristics of offspring. Francis Galton studied in a large number of families the relations between the average height of the parents and the average height of the adult children. Some of these relations appear in the following table:

AVERAGE HEIGHT OF PARENTS		AVERAGE HEIGHT OF CHILDREN
72.5		71.4
71.5		69.9
70.5		69.5
69.5		68.6
68.5		68.0
67.5		67.6
66.5		67.1
65.5		66.8
64.5		65.6

In no case is the average height of the children widely different from that of the parents. It is evident that children of tall parents are likely to be tall, though not averaging as tall as their parents, and that children of short parents are likely to be

short, though not averaging as short as their parents. It must be understood that there may be exceptionally tall or exceptionally short children in any family and that such cases are included in the averages given.

498. Heredity and the future of the race. Few things contribute more to successful living than a sound and vigorous body, and such is a heritage of untold value. An unsound body is also a heritage, but a burdensome one. We cannot emphasize too strongly the importance of making sure that no avoidable tendency to disease and no abnormally weakened bodies are passed on to succeeding generations. There are few tragedies more awful than that of being born into the world weighted down with a weakened body. Such bodies are given to innocent people because parents or society did not know enough or care enough to prevent the inheritance of things that make successful life hard, often well-nigh impossible, for the offspring. It is very important that the human race should recognize and use what is known of biological inheritance. High types of corn and cattle have been developed and are constantly being improved because men wish to profit from these better types. It is apparently easier for men to see and appreciate the advantages from better cattle and pigs than to see the advantage in improving the quality of the succeeding generations of the human race. What are we doing to make sure that the next generation of men and women shall be physically, intellectually, and morally as effective as the laws of heredity will enable us to make them?

499. Controlling human environment. No one of us can now determine what our own inheritance shall be. That has been settled for us. We can decide to some extent what shall be the heredity of those who are to come after us. We can do much toward changing our environment and our habits so that defects in our own heredity may not lead to consequences as undesirable as might otherwise result.

A weakened body may often be strengthened by judicious care and exercise so that a hereditary weakness may be almost

or entirely overcome. It is sometimes possible to curb an undesirable hereditary tendency until it almost or quite loses its influence. We can create for ourselves new and artificial environments and new habits which may enable us to turn a harmful or worthless hereditary tendency into efficiency and a high type of usefulness. It is a heavy task to "stem the tide" of nature, and he who would do it must prepare for a determined effort in which some have failed and some have succeeded. It is worth the effort, for what is better than to turn weakness into efficiency?

Good inheritance, good environment, and good habits, like their opposites, produce results which increase as they continue to operate. One of the most encouraging aspects of the question is found in the fact that the longer the above qualities work the more momentum they seem to acquire. The prolonged and helpful influence of good inheritance and properly controlled selection seems to be just as natural and enduring and to produce a tide of nature which carries individuals with it as truly as does the tide produced by unfavorable inheritance and habits.

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